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(54) **PROCESSING TEXT IMAGES WITH SHADOWS**

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G06K 9/38	(2006.01)
G06K 9/18	(2006.01)
G06T 7/00	(2006.01)

(52) **U.S. Cl.**

CPC . ***G06K 9/18*** (2013.01); ***G06K 9/38*** (2013.01); ***G06T 7/0079*** (2013.01); *G06T 2207/20021* (2013.01); *G06T 2207/30244* (2013.01)

(58) **Field of Classification Search**

CPC G06K 9/18; G06K 9/38; G06T 2207/30244; G06T 2207/20021; G06T 7/0079

USPC 382/165

See application file for complete search history.

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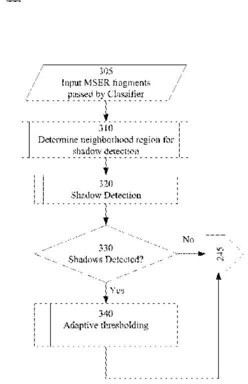
(57) **ABSTRACT**

Embodiments disclosed facilitate robust, accurate, and reliable recovery of words and/or characters in the presence of non-uniform lighting and/or shadows. In some embodiments, a method to recover text from image may comprise: expanding a Maximally Stable Extremal Region (MSER) in an image, the neighborhood comprising a plurality of sub-blocks; thresholding a subset of the plurality of sub-blocks in the neighborhood, the subset comprising sub-blocks with text, wherein each sub-block in the subset is thresholded using a corresponding threshold associated with the sub-block; and obtaining a thresholded neighborhood.

28 Claims, 13 Drawing Sheets


300
305
Input MSER fragments passed by Classifier
310
Determine neighborhood region for shadow detection
320
Shadow Detection
330
Shadows Detected?
No
245
Yes
340
Adaptive thresholding

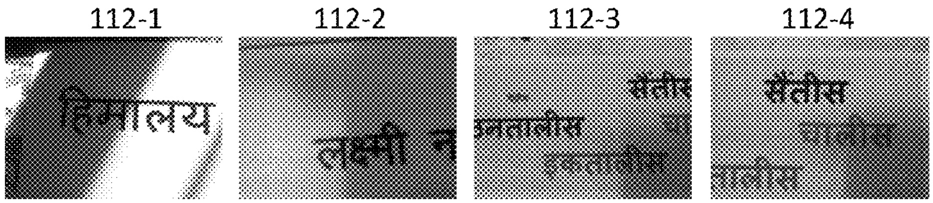

112-1
112-2
112-3
112-4
हिमालय

Fig. 1A

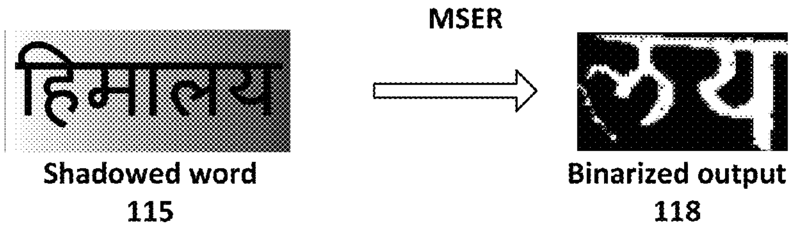

MSER
हिमालय
Shadowed word
115
Binarized output
118

Fig. 1B

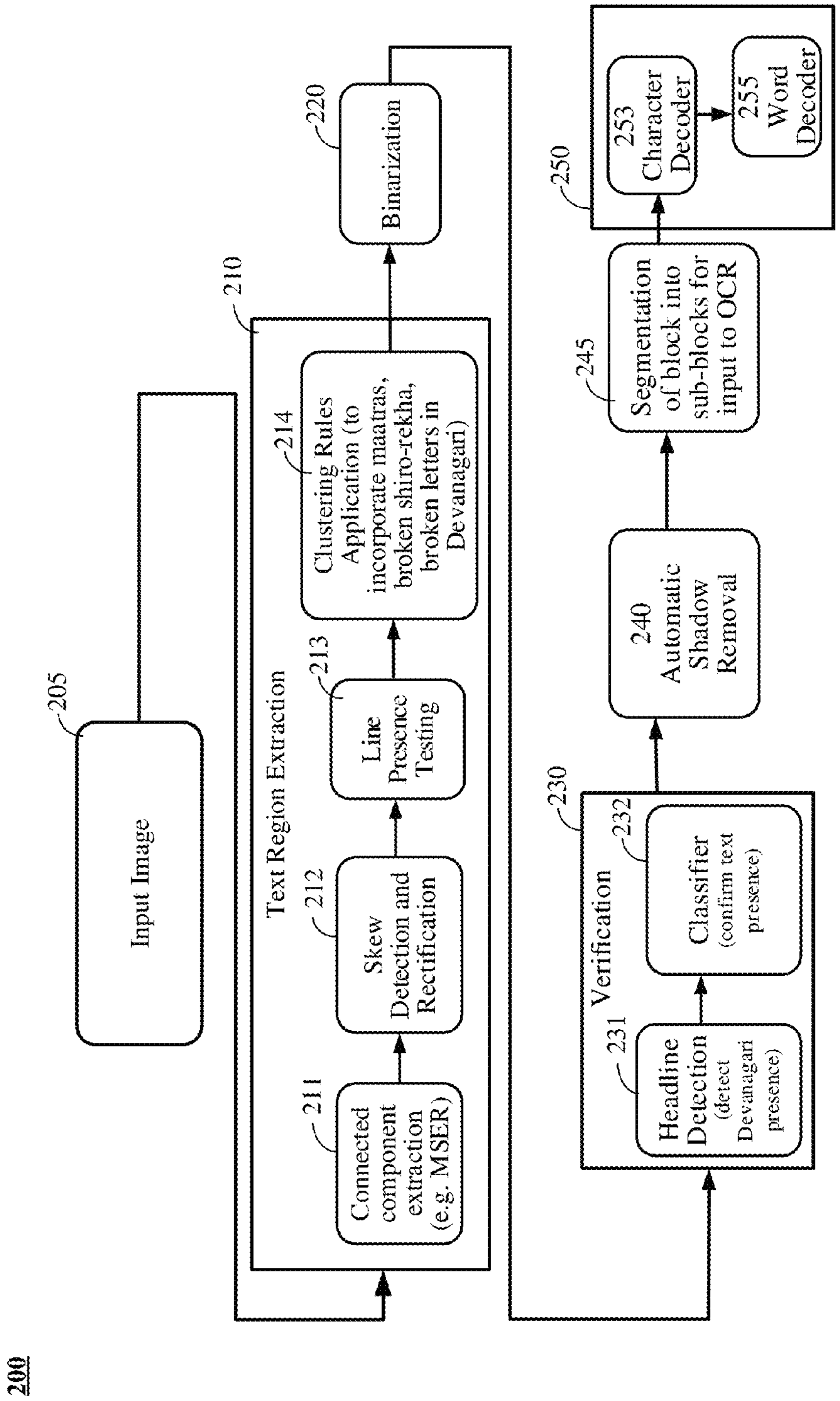

200
205
Input Image
210
Text Region Extraction
211
Connected component extraction (e.g. MSER)
212
Skew Detection and Rectification
213
Line Presence Testing
214
Clustering Rules Application (to incorporate maatras, broken shiro-rekha, broken letters in Devanagari)
220
Binarization
230
Verification
231
Headline Detection (detect Devanagari presence)
232
Classifier (confirm text presence)
240 Automatic Shadow Removal
245
Segmentation of block into sub-blocks for input to OCR
250
253 Character Decoder
255 Word Decoder

Fig. 2

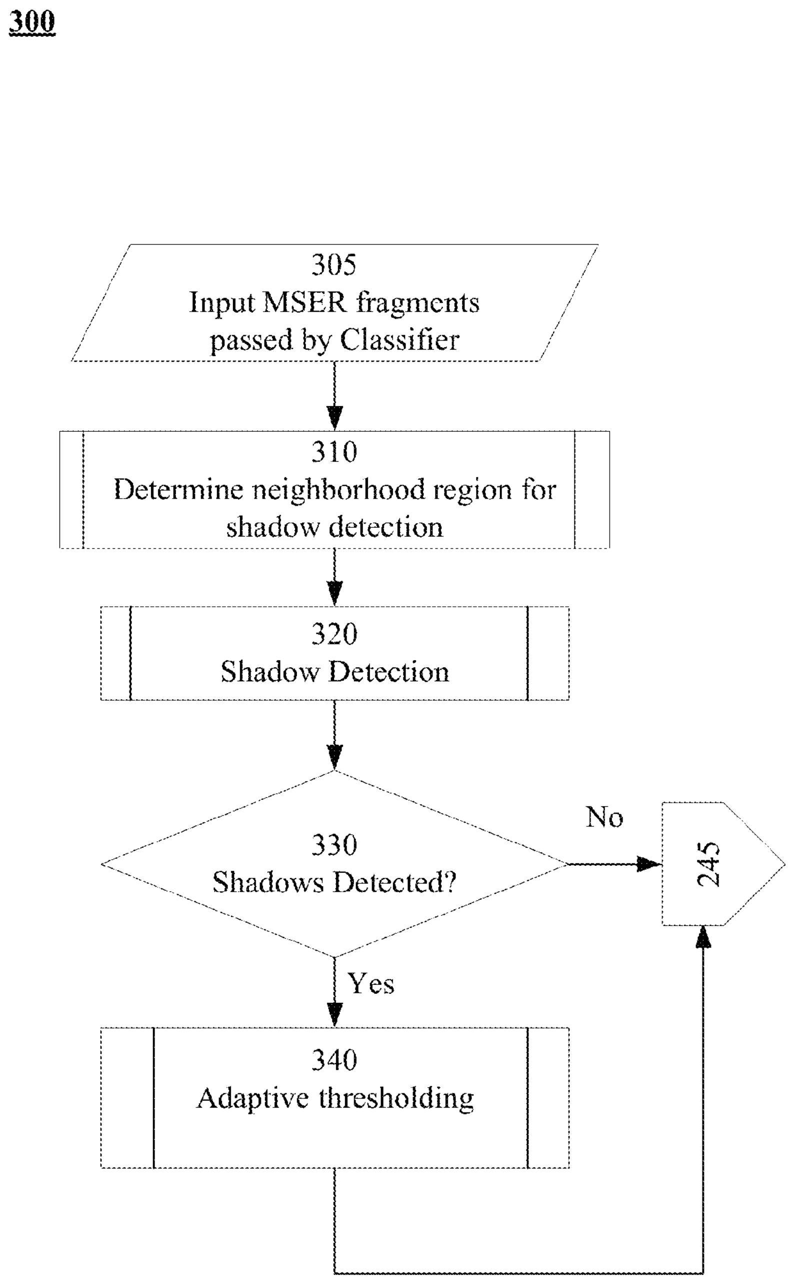

300
305
Input MSER fragments passed by Classifier
310
Determine neighborhood region for shadow detection
320
Shadow Detection
330
Shadows Detected?
No
245
Yes
340
Adaptive thresholding

Fig. 3

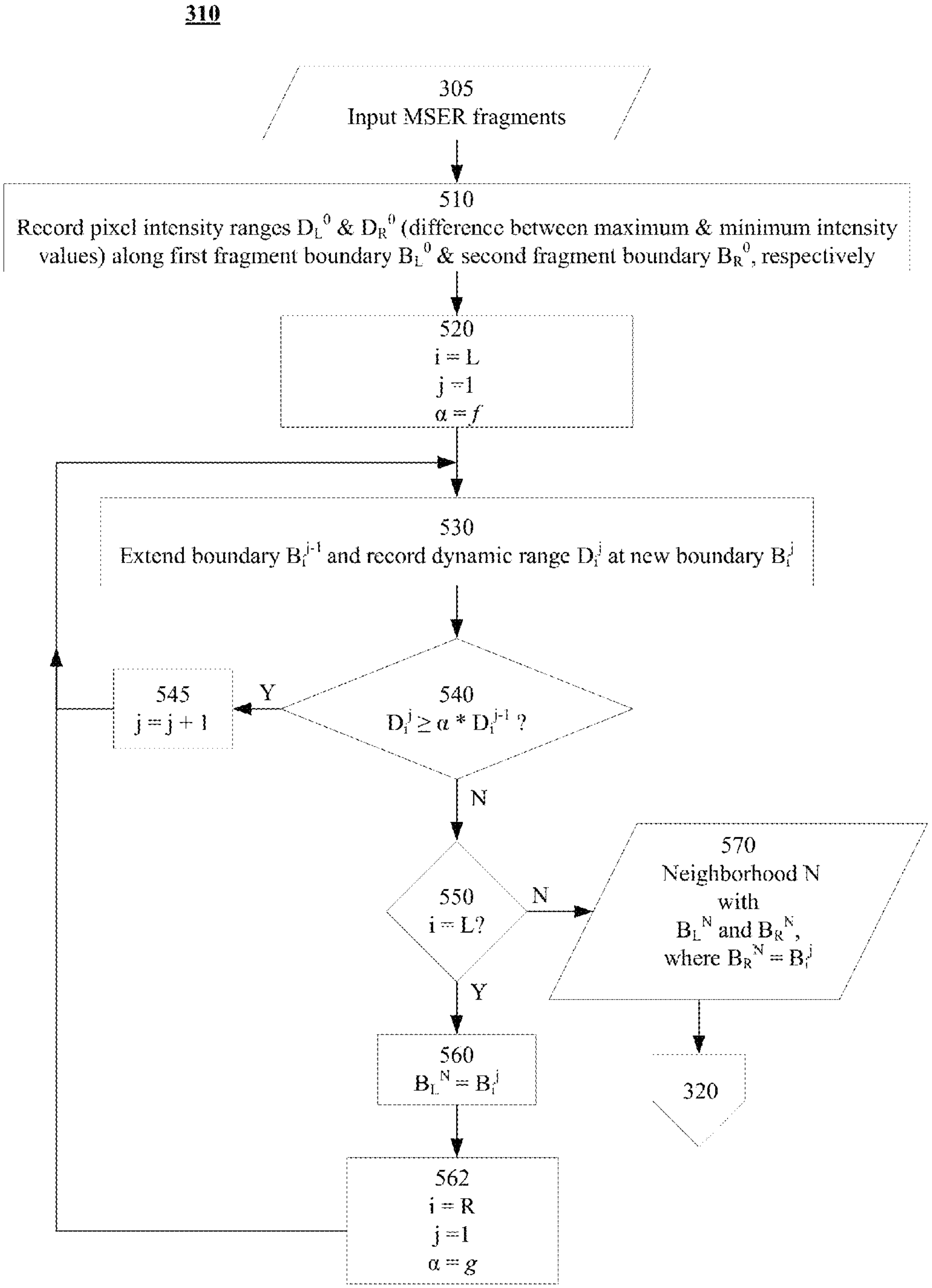

310
305
Input MSER fragments
510
Record pixel intensity ranges D_L^0 & D_R^0 (difference between maximum & minimum intensity values) along first fragment boundary B_L^0 & second fragment boundary B_R^0, respectively
520
i = L
j =1
$\alpha = f$
530
Extend boundary B_i^{j-1} and record dynamic range D_i^j at new boundary B_i^j
540
$D_i^j \geq \alpha * D_i^{j-1}$?
Y
545
j = j + 1
N
550
i = L?
N
570
Neighborhood N
with
B_L^N and B_R^N,
where $B_R^N = B_i^j$
320
Y
560
$B_L^N = B_i^j$
562
i = R
j =1
$\alpha = g$

Fig. 4A

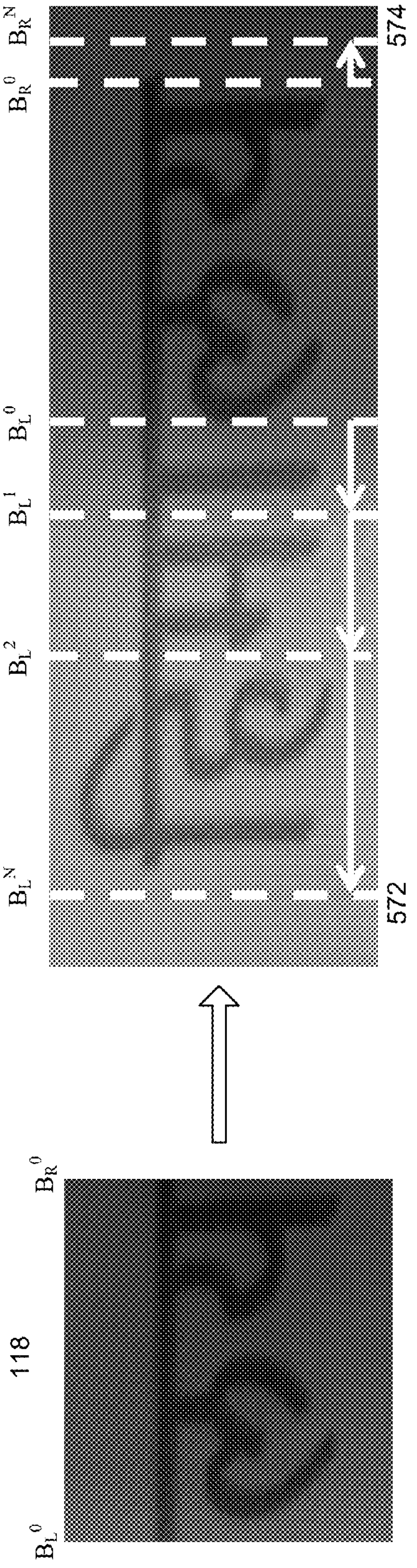


Fig. 4B

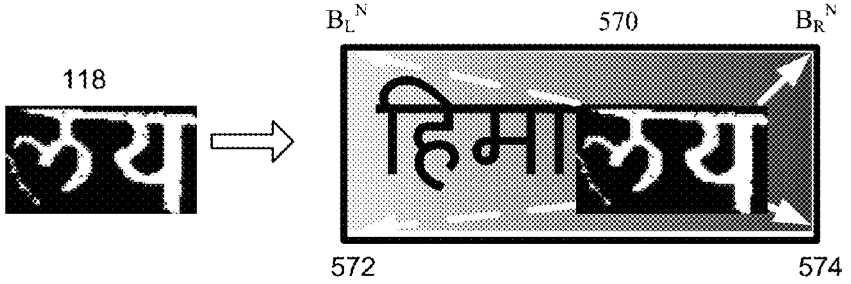


Fig. 4C

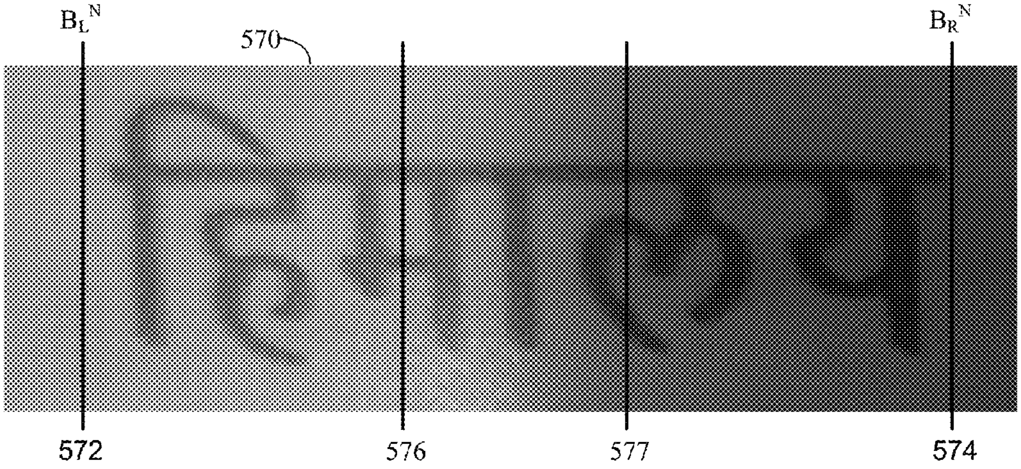


Fig. 4D

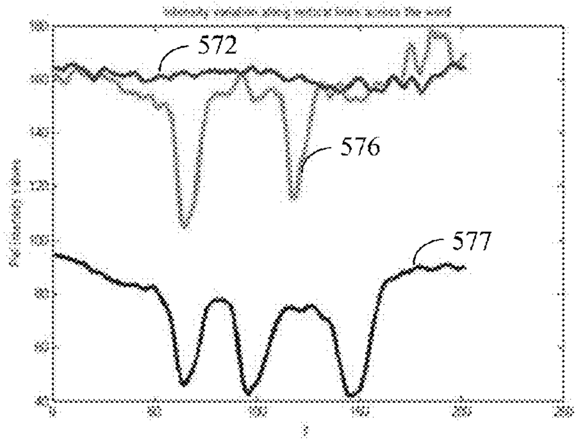


Fig. 4E

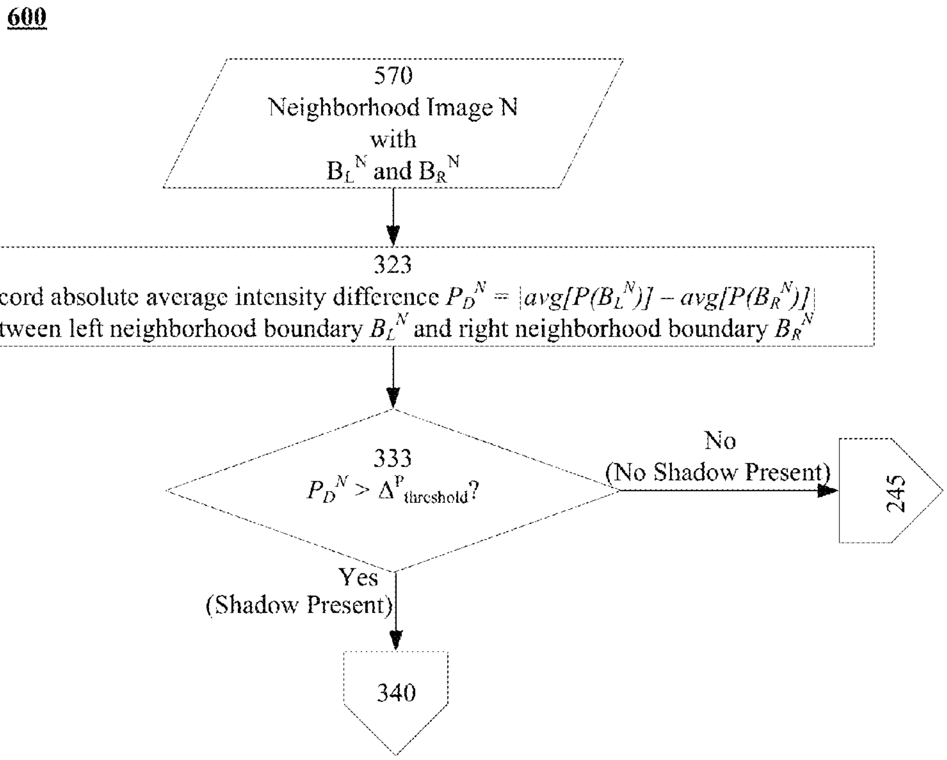

600
570
Neighborhood Image N
with
B_L^N and B_R^N
323
Record absolute average intensity difference $P_D^N = |avg[P(B_L^N)] - avg[P(B_R^N)]|$
between left neighborhood boundary B_L^N and right neighborhood boundary B_R^N
333
$P_D^N > \Delta^P_{threshold}$?
No
(No Shadow Present)
245
Yes
(Shadow Present)
340

Fig. 5A

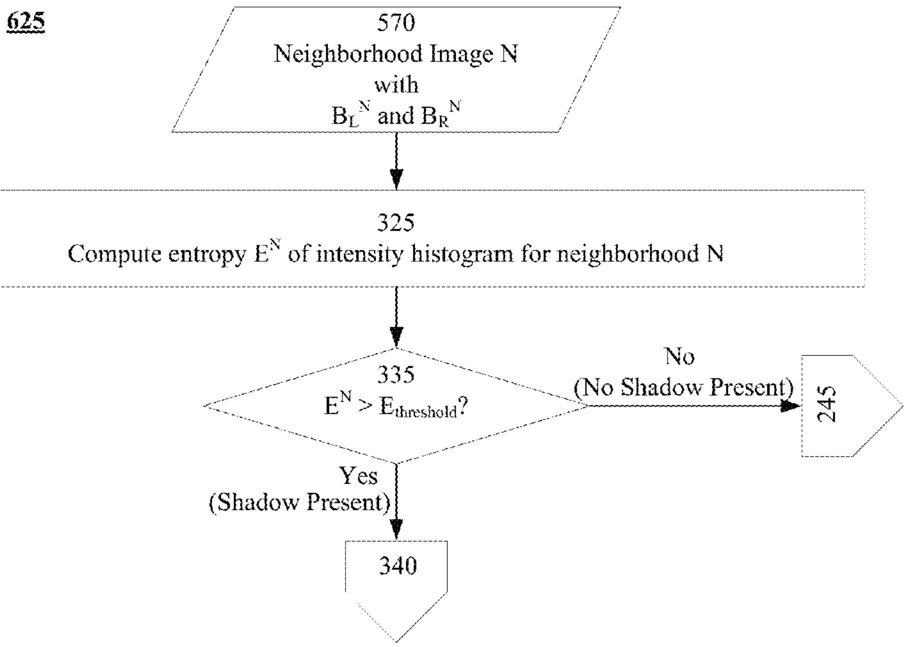

625
570
Neighborhood Image N
with
B_L^N and B_R^N
325
Compute entropy E^N of intensity histogram for neighborhood N
335
$E^N > E_{threshold}$?
No
(No Shadow Present)
245
Yes
(Shadow Present)
340

Fig. 5B

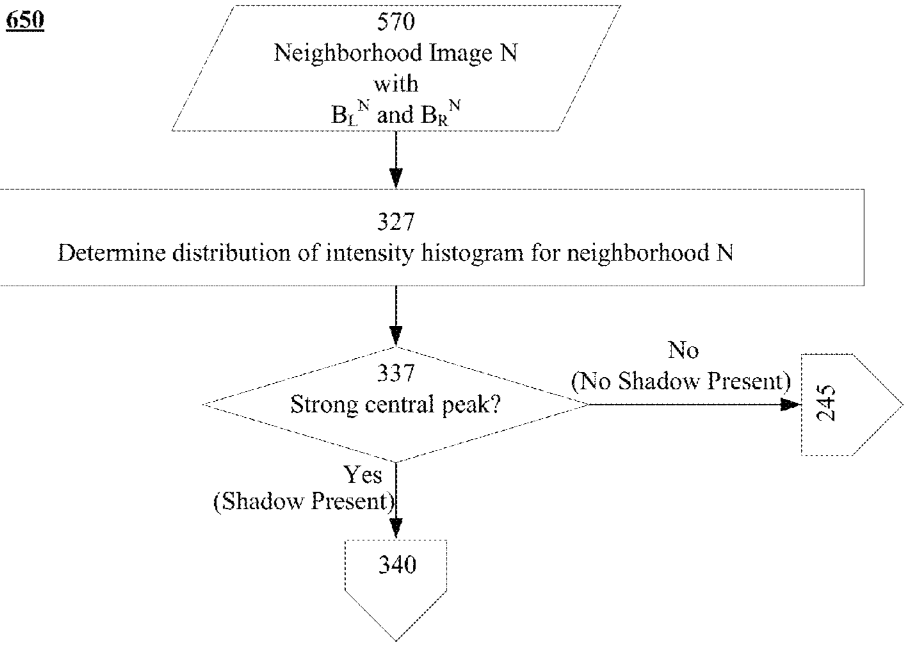

650
570
Neighborhood Image N
with
B_L^N and B_R^N
327
Determine distribution of intensity histogram for neighborhood N
337
Strong central peak?
No
(No Shadow Present)
245
Yes
(Shadow Present)
340

Fig. 5C

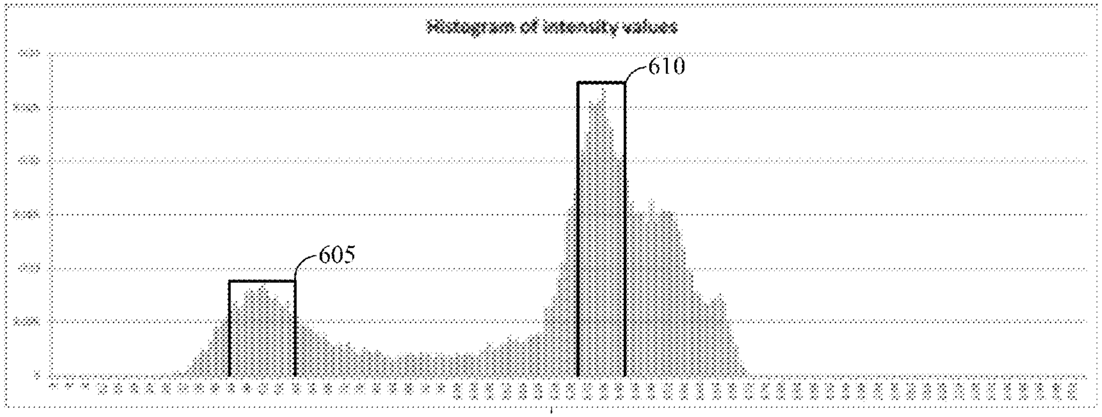

Histogram of intensity values
605
610

Fig. 5D

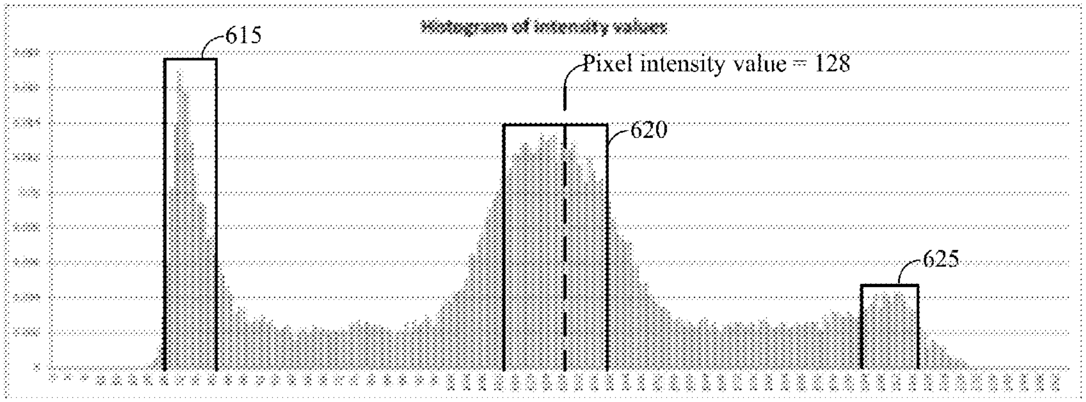

Histogram of intensity values
615
Pixel intensity value = 128
620
625

Fig. 5E

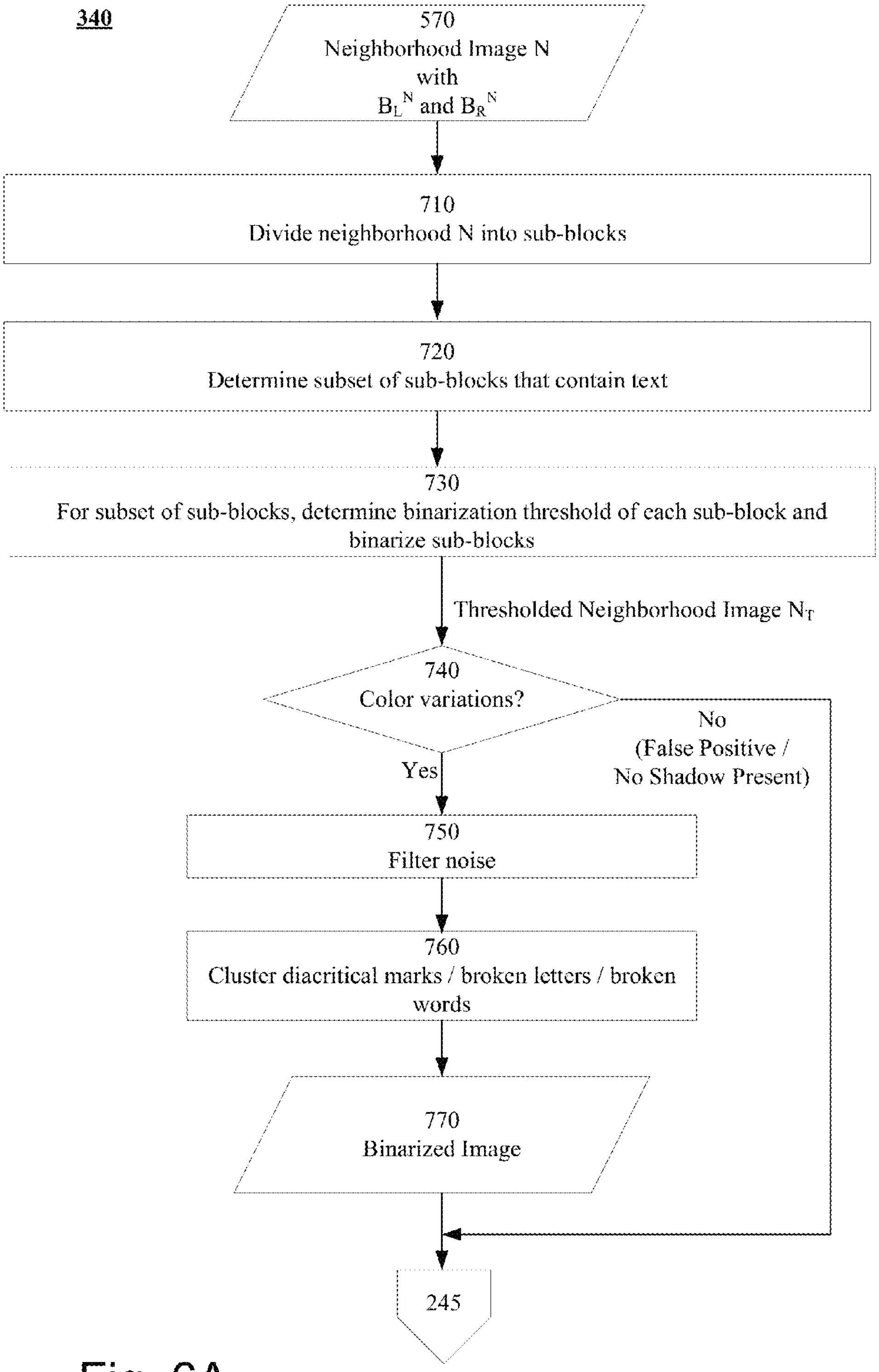

340
570
Neighborhood Image N
with
B_L^N and B_R^N
710
Divide neighborhood N into sub-blocks
720
Determine subset of sub-blocks that contain text
730
For subset of sub-blocks, determine binarization threshold of each sub-block and binarize sub-blocks
Thresholded Neighborhood Image N_T
740
Color variations?
Yes
No
(False Positive /
No Shadow Present)
750
Filter noise
760
Cluster diacritical marks / broken letters / broken words
770
Binarized Image
245

Fig. 6A

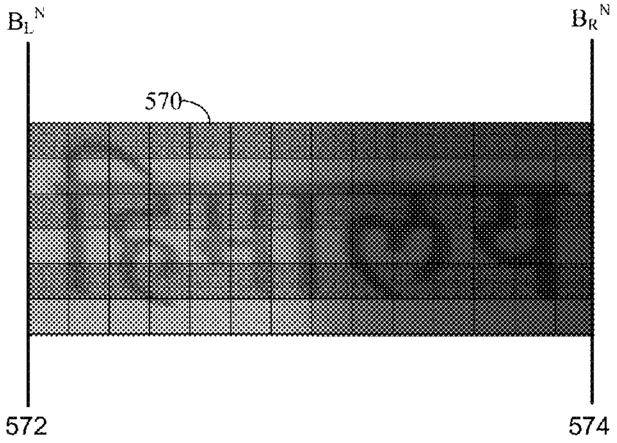

B_L^N
B_R^N
570
572
574

Fig. 6B

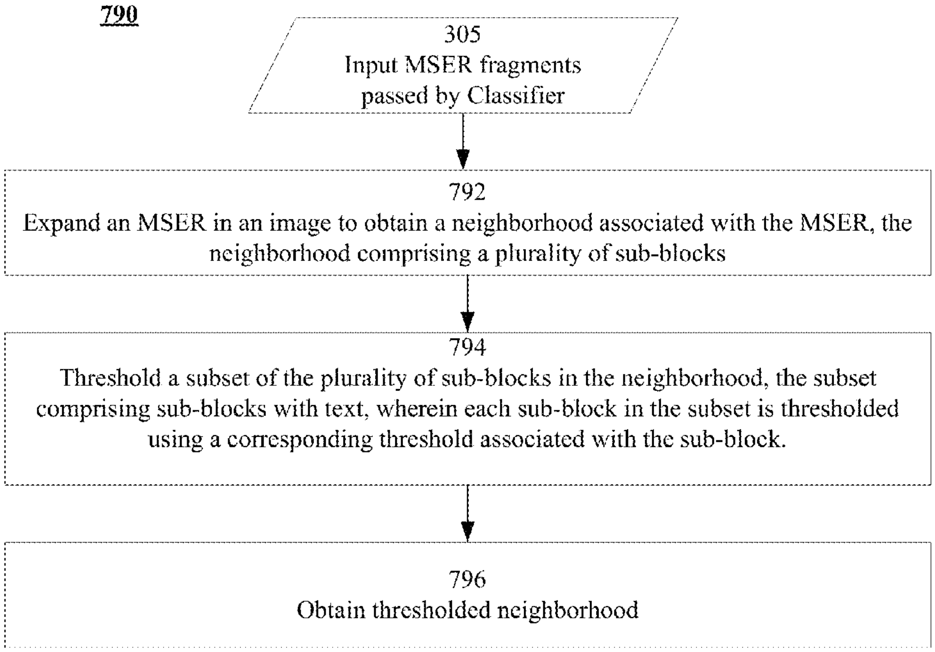

790
305
Input MSER fragments passed by Classifier
792
Expand an MSER in an image to obtain a neighborhood associated with the MSER, the neighborhood comprising a plurality of sub-blocks
794
Threshold a subset of the plurality of sub-blocks in the neighborhood, the subset comprising sub-blocks with text, wherein each sub-block in the subset is thresholded using a corresponding threshold associated with the sub-block.
796
Obtain thresholded neighborhood

Fig. 6C

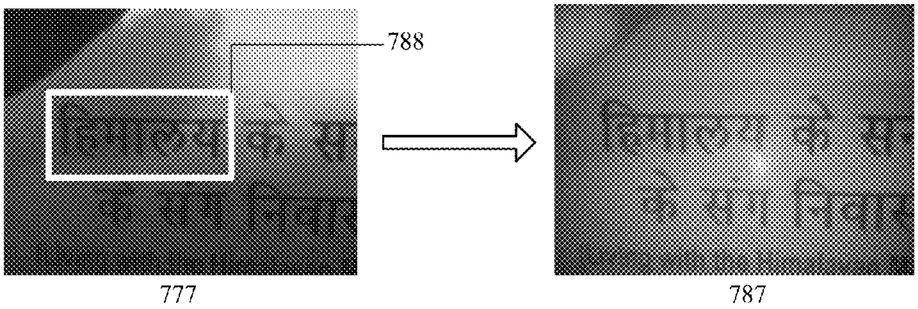

788
777
787

Fig. 7A

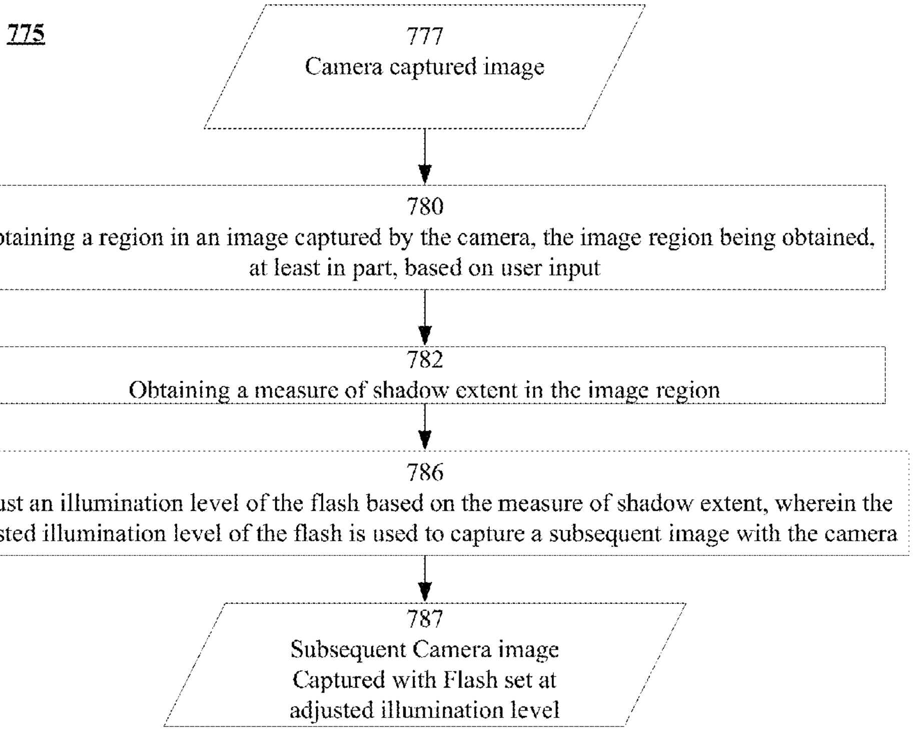

775
777
Camera captured image
780
Obtaining a region in an image captured by the camera, the image region being obtained, at least in part, based on user input
782
Obtaining a measure of shadow extent in the image region
786
Adjust an illumination level of the flash based on the measure of shadow extent, wherein the adjusted illumination level of the flash is used to capture a subsequent image with the camera
787
Subsequent Camera image Captured with Flash set at adjusted illumination level

Fig. 7B

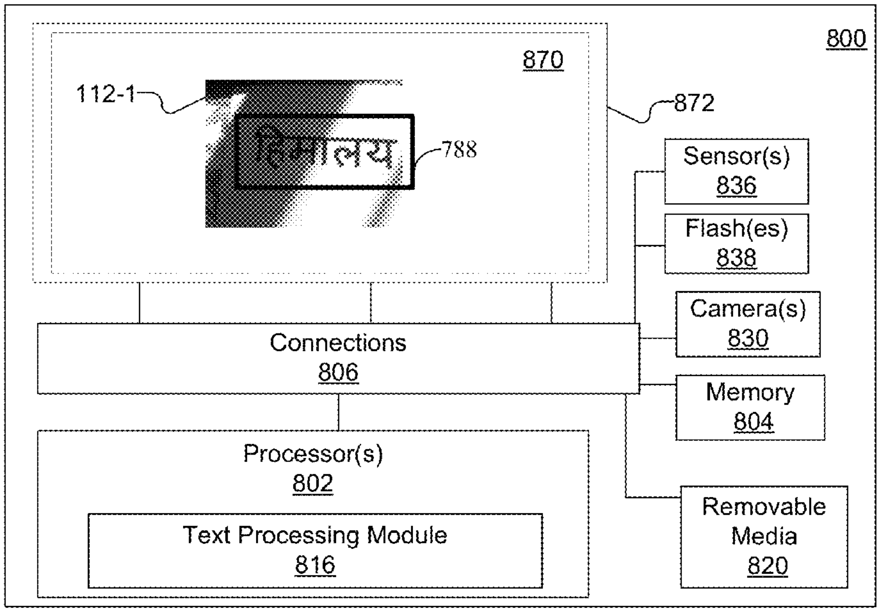

800
870
872
112-1
हिमालय
788
Sensor(s)
836
Flash(es)
838
Camera(s)
830
Memory
804
Connections
806
Processor(s)
802
Text Processing Module
816
Removable
Media
820

Fig. 8

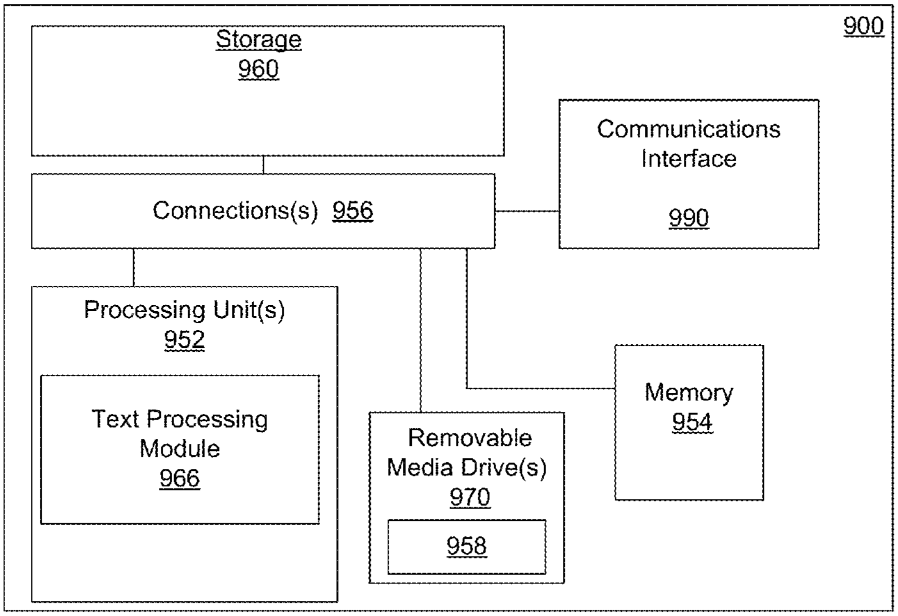

900
Storage
960
Communications
Interface
990
Connections(s) 956
Processing Unit(s)
952
Text Processing
Module
966
Removable
Media Drive(s)
970
958
Memory
954

Fig. 9

PROCESSING TEXT IMAGES WITH SHADOWS

FIELD

The subject matter disclosed herein relates to Optical Character Recognition, and in particular to Optical Character Recognition in the presence of non-uniform lighting.

BACKGROUND

The presence of non-uniform lighting and/or shadows, which create variations in image intensity levels, may detrimentally affect the reliability of Optical Character Recognition (OCR) techniques applied to the images. In many OCR approaches, text is recognized in an image by localizing each word and/or character in the image, which is followed by classification of the word and/or character. Recent localization techniques have focused on pixel grouping/merging approaches because they yield good text localization results with relatively low computational overhead.

For example, Maximally Stable Extremal Regions (MSER) based methods are often used for character segmentation during OCR. MSER based methods typically identify regions of contiguous pixel sets (termed "Connected Components"), whose pixel intensities differ from pixel intensities within a region bounded by the Connected Component (CC) by some predetermined threshold, and where the size of the CC is stable across several intensity thresholds. MSERs may be viewed as CCs, where pixels inside the CC have either higher or lower intensity than all pixels on the CC.

Because MSER identification is dependent on pixel intensities, the presence of shadows or non-uniform lighting in images may impact the identification of CCs. The term "shadows" as used herein refers broadly to variations in pixel intensities caused by non-uniform lighting and/or contrast variations. For example, when shadows are present, only a portion of a word in an image may be obtained as a connected component, thereby leading to errors or inaccuracies in the OCR process.

Therefore, there is a need for systems, apparatus and methods that facilitate robust and accurate recovery of words and/or characters reliably in the presence of non-uniform lighting and/or shadows.

SUMMARY

In some embodiments, a method may comprise: expanding a Maximally Stable Extremal Region (MSER) in an image to obtain a neighborhood associated with the MSER, the neighborhood comprising a plurality of sub-blocks; thresholding a subset of the plurality of sub-blocks in the neighborhood, the subset comprising sub-blocks with text, wherein each sub-block in the subset is thresholded using a corresponding local threshold associated with the sub-block and obtaining a thresholded neighborhood.

In a further aspect, a method performed on a mobile station (MS) comprising a camera coupled to a flash may comprise: obtaining a region in an image captured by the camera, the image region being obtained, at least in part, based on user input; obtaining a measure of shadow extent in the image region; and adjusting an illumination level of the flash based on the measure of shadow extent, wherein the adjusted illumination level of the flash is used to capture a subsequent image with the camera. In some embodiments, the measure of shadow extent may be obtained based, at least in part, on at least one of: a comparison of an absolute average pixel intensity difference between the first and second boundaries with an intensity difference threshold; or a comparison of an entropy of a pixel intensity histogram for the neighborhood with an entropy threshold; or an analysis of a pixel intensity distribution in the pixel intensity histogram for the neighborhood.

In another aspect, a Mobile Station (MS) may comprise: a camera, the camera to capture an image, and a processor coupled to the camera. In some embodiments, the processor may be configured to: expand a Maximally Stable Extremal Region (MSER) in the image to obtain a neighborhood associated with the MSER, the neighborhood comprising a plurality of sub-blocks; thresholding a subset of the plurality of sub-blocks in the neighborhood, the subset comprising sub-blocks with text, wherein each sub-block in the subset is thresholded using a corresponding local threshold associated with the sub-block; and obtaining a thresholded neighborhood.

In another aspect, a Mobile Station (MS) may comprise: a camera, the camera to capture an image of an environment, a flash coupled to the camera, the flash to illuminate the environment in conjunction with the capture of the image by the camera based an illumination level associated with the camera, a processor coupled to the camera and the flash. In some embodiments, the processor may be configured to: obtain a region in an image captured by the camera, the image region being obtained, at least in part, based on user input; obtain a measure of shadow extent in the image region; and adjust an illumination level of the flash level based, at least in part, on the measure of shadow extent. In some embodiments, the processor may be configured to determine the measure of shadow extent based, at least in part, on at least one of: a comparison of an absolute average pixel intensity difference between the first and second boundaries with an intensity difference threshold; or a comparison of an entropy of a pixel intensity histogram for the neighborhood with an entropy threshold; or an analysis of a pixel intensity distribution in the pixel intensity histogram for the neighborhood.

Embodiments disclosed also pertain to an apparatus comprising: image obtaining means, the image obtaining means to obtain an image, and text processing means coupled to the image obtaining means. In some embodiments, the text processing means may further comprise: means for expanding a Maximally Stable Extremal Region (MSER) in the image to obtain a neighborhood associated with the MSER, the neighborhood comprising a plurality of sub-blocks; means for thresholding a subset of the plurality of sub-blocks in the neighborhood, the subset comprising sub-blocks with text, wherein each sub-block in the subset is thresholded using a corresponding local threshold associated with the sub-block; and means for obtaining a thresholded neighborhood.

In another embodiment, an apparatus may comprise: imaging means, the imaging means to capture an image of an environment; illumination means coupled to the imaging means, the illumination means to illuminate the environment in conjunction with the capture of the image by the imaging means based an illumination level associated with the imaging means; and text processing means coupled to the imaging means. In some embodiments, the text processing means may further comprise: means for obtaining a region in an image captured by the imaging means, the image region being obtained, at least in part, based on user input; means for obtaining a measure of shadow extent in the image region; and means for adjusting an illumination level of the flash level based, at least in part, on the measure of shadow extent. In some embodiments, the means for obtaining a measure of shadow extent in the image region may determine the measure of shadow extent is obtained based, at least in part, on at least one of: a comparison of an absolute average pixel intensity difference between the first and second boundaries with an intensity difference threshold; or a comparison of an entropy of a pixel intensity histogram for the neighborhood with an entropy threshold; or an analysis of a pixel intensity distribution in the pixel intensity histogram for the neighborhood.

Embodiments disclosed pertain to a computer-readable medium comprising instructions, which when executed by a processor, perform steps in a method comprising: expanding a Maximally Stable Extremal Region (MSER) in an image to obtain a neighborhood associated with the MSER, the neighborhood comprising a plurality of sub-blocks; thresholding a subset of the plurality of sub-blocks in the neighborhood, the subset comprising sub-blocks with text, wherein each sub-block in the subset is thresholded using a corresponding local threshold associated with the sub-block; and obtaining a thresholded neighborhood.

Embodiments disclosed also pertain to a computer-readable medium comprising instructions, which when executed by a processor on a mobile station (MS) comprising a camera coupled to a flash, performs steps in a method comprising: obtaining a region in an image captured by the camera, the image region being obtained, at least in part, based on user input; obtaining a measure of shadow extent in the image region; and adjusting an illumination level of the flash based on the measure of shadow extent, wherein the adjusted illumination level of the flash is used to capture a subsequent image with the camera. In some embodiments, the measure of shadow extent is obtained based, at least in part, on at least one of: a comparison of an absolute average pixel intensity difference between the first and second boundaries with an intensity difference threshold; or a comparison of an entropy of a pixel intensity histogram for the neighborhood with an entropy threshold; or an analysis of a pixel intensity distribution in the pixel intensity histogram for the neighborhood.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1**A shows several exemplary images containing shadows.

FIG. **1**B shows a binarized output image obtained when conventional MSER techniques are applied to binarize an exemplary image containing shadows.

FIG. **2** shows a high level block diagram of modules of an OCR system consistent with disclosed embodiments.

FIG. **3** shows a flowchart of an exemplary method **300** for processing text in the presence of shadows in a manner consistent with disclosed embodiments.

FIG. **4**A shows a flowchart of an exemplary method **310** for determining a neighborhood region around an MSER fragment in a manner consistent with disclosed embodiments.

FIG. **4**B illustrates expansion of the boundaries exemplary binarized output MSER fragment.

FIG. **4**C illustrates the result of expanding exemplary binarized output fragment to a neighborhood region.

FIG. **4**D shows illustrates image intensities at the left and right boundaries of a neighborhood image around an MSER fragment.

FIG. **4**E shows a graph plotting image intensities at three locations for the neighborhood shown in FIG. **4**B.

FIGS. **5**A, **5**B and **5**C shows a flowcharts of exemplary methods **600**, **625**, and **650**, respectively, for determining the presence of shadows in a neighborhood region around an MSER fragment in a manner consistent with disclosed embodiments

FIG. **5**D shows a histogram of pixel intensity values in a neighborhood region around an MSER fragment for an exemplary image without a shadow.

FIG. **5**E shows a histogram of pixel intensity values in a neighborhood region around an MSER fragment for an exemplary image with a shadow.

FIG. **6**A shows a flowchart for an exemplary method for adaptive thresholding in a manner consistent with disclosed embodiments.

FIG. **6**B shows exemplary neighborhood N **570** with boundaries B_L^N **572** and B_R^N **574** divided into equal sized sub-blocks.

FIG. **6**C shows an exemplary flowchart for a method of processing text in the presence of shadows and/or non-uniform lighting conditions in a manner consistent with disclosed embodiments.

FIG. **7**A shows a camera captured image and a camera image captured with the flash set at an adjusted illumination level.

FIG. **7**B shows a method for compensating for the presence of shadows and/or non-uniform lighting in a camera captured image.

FIG. **8** shows an exemplary Mobile Station (MS) capable of processing text in the presence of shadows in a manner consistent with disclosed embodiments.

FIG. **9** shows an exemplary server capable of processing text in the presence of shadows in a manner consistent with disclosed embodiments

DETAILED DESCRIPTION

FIG. **1**A shows several exemplary images **112-1**, **112-2**, **112-3** and **112-4** containing shadows. In situations where a real-world image is captured by a Mobile Station (MS) and/or a camera or an image sensor, such as images of billboards, road signs, informational signs, etc., the presence of shadows, non-uniform lighting and/or contrast variations is more likely. In general, whenever a user has limited control over an environment in which images are being captured, the presence of shadows/non-uniform lighting/contrast variations cannot be ruled out. When shadows, contrast variations and/or non-uniform lighting are present in images the accuracy and reliability of OCR techniques may be affected. The term "shadows" as used herein refers broadly to variations in image intensities such as may be caused by non-uniform lighting and/or contrast variations.

FIG. **1**B shows a binarized output image obtained when conventional MSER techniques are applied to binarize an exemplary image containing shadows. As shown in FIG. **1**B, the presence of shadows and/or non-uniform lighting may affect the detection of MSERs in shadowed image **115** resulting in a partial detection of the word. For example, as shown in FIG. **1**B, when conventional MSER based techniques are used for shadowed word "हिमालय" **115**, the binarized output **118** may not contain the entire word. For example, as shown in FIG. **1**B, the binarized output "लय" **118**, may comprise a portion of shadowed word "हिमालय" **115**. Therefore, embodiments disclosed herein facilitate robust, accurate, and reliable recovery of words and/or characters in the presence of non-uniform lighting and/or shadows.

FIG. **2** shows a high level block diagram of modules of an exemplary OCR system **200** consistent with disclosed embodiments. In some embodiments, the modules may be implemented by some combination of hardware, software and/or firmware.

As shown in FIG. **2**, exemplary OCR system **200**, which may operate on input image **205**, may comprise text region extraction module **210**, binarization module **220**, verification module **230**, automatic shadow removal module **240**, segmentation module **245**, and text recognition module **250**. The modules and/or functional blocks shown in FIG. **2** are illustrative and for descriptive purposes only. System **200** may comprise various other modules/functional blocks and/or the functionality associated with the modules/functional blocks may be changed in various ways to achieve functionality consistent with disclosed embodiments.

Text region extraction module **210** may extract one or more regions from image **205**, based, for example, on variations in pixel intensities I(x) for points x in image **205**. Text extraction module may comprise connected component extraction module **211**, skew detection and rectification module **212**, line presence testing module **213** and clustering rules module **214**.

Connected component extraction module **211** may extract connected components from image **205**. In some embodiments, MSER based techniques may be used to extract connected components. MSER techniques may be used to generate a binary image B from image **205** by considering a plurality of thresholds T, so that for each threshold T, the pixel intensity $P_T(x)$ for a pixel x in binary image B is given by

$$P_T(x) = \begin{cases} 1, & I(x) \geq T \\ 0, & \text{otherwise} \end{cases}$$

MSERs are connected regions which are stable over a large number of thresholds. For example, in one embodiment, to determine MSERs, pixels x may be ordered by increasing intensity values I(x). Then, the threshold T may be iteratively increased (e.g. by some value Δ_T) and corresponding pixels may added to the binary image B_T and a list of connected components may be returned. The term "connected component" refers to groups of connected pixels that exhibit similar intensity values. In general, connected components may be extracted by connected component extraction module **211** using any appropriate MSER method.

Skew detection and rectification module **212** may rotate identified MSERs to align them to an axis and correct skew. For example, after one or more MSERs in an input image are identified by connected component extraction module **211**, skew detection and rectification module **212** may perform skew presence detection followed by skew rectification.

During skew detection, a skew value indicative of skew magnitude M, local to a specific MSER Q_i, may be computed, where Q is the set of MSERs and $Q_i \epsilon Q$. In some embodiments, the skew value for an MSER Q_i may be computed, in part, by using: (i) a rectangle or bounding box that fits MSER Q_i, which in some instances, may take the form of a "minimum bounding rectangle" and (ii) a count of pixels in MSER Q_i. Thereafter, in some embodiments, a number of angles that are candidates for use as skew may be determined based on locations of pixels within the minimum bounding rectangle/bounding box for MSER Q_i. Then, a skew angle relative to the axis that is most common across MSERs among these candidate skew angles, may be identified as the angle of skew of the image. In some embodiments, a value of an indicator of skew for each MSER Q_i may be stored either individually (for each region) or in aggregate (across multiple regions), at a specific location in memory **501**. In some embodiments, the individual skew values may be used to determine whether skew is present globally, in the image as a whole. For example, statistical methods may be used to compute a mean or a median of the multiple values, followed by filtering outliers among the multiple values, followed by re-computation of mean or median of the filtered values and comparison to a threshold to determine whether or not skew in the image as a whole is acceptable. In general, various known techniques for skew detection and rectification may be used to obtain a skew angle. In some embodiments, connected components and/or MSER regions in the image may be rotated by the negative of the skew angle during rectification.

Next, line presence testing module **213** may determine the presence of a line of pixels of a common intensity value. For example, in many Brahmi scripts, such as the Devanagari family of scripts, a head line (also termed a "shiro-rekha") is used to identify characters that represent a single word. In some embodiments, line presence testing module **213** may be used to determine the presence of lines, including head lines or shiro-rekhas in MSERs.

In some embodiments, clustering rules module **214** may merge a plurality of CCs that are part of a word into a new single clustered connected component when one of the regions satisfies the test for line presence. For example, in Devanagari, two or more CCs, which may be part of a single word, may be disconnected because of diacritical marks and/or the use of half-letters. Diacritical marks (which are also called "maatras") may comprise marks to indicate vowel sounds that are placed in close proximity to base letters often lead to more than one CC for a word. As another example, some letters in Devanagari, such as "श" may create a break in the ShiroRekha and lead to two CCs. Further, the use of half-letters such as in the word ""फुल्का" may also create a plurality of CCs for a single word. Accordingly, clustering rules module **214** may use context, language dependent, and other rules to cluster a plurality of CCs that are part of a word to form a new single clustered connected component.

For example, in one embodiment, CCs in one or more MSERs, which satisfy the test for line presence and are located physically adjacent to a first MSER may be merged with a CC in the first MSER. The CCs may be merged, for instance, when they are sufficiently close to one another as indicated by a specific tests and/or conditions. For example, merging may occur when a distance (or separation) between the CCs is less than the height of the MSERs that satisfy the line presence test).

In some embodiments, Binarization module **220** may operate on the image output by text region extraction module **210** based on the text and background information obtained from the MSER blocks to threshold the image into black and white. In some embodiments, binarization module **220** may binarize regions within bounding boxes (clustered or unclustered) output by clustering rules module **214**.

Verification module **230** may then operate on the binarized image output by block **220**. In some embodiments, verification module **230** may comprise headline detection module **231**, which may verify that a line of pixels of a common binary value is present in the binarized block of a region (whether or not clustered), and classifier module **232**, which may classify binarized blocks as text or non-text. In some embodiments, verification module **230** may use various other distinguishing characteristics associated with a language and/or characters in the language to verify the presence of characters in a language. In some embodiments, classifier module may take the form of a neural network classifier, which may learn representations of input that determine the presence of characters. In some embodiments, the classification may be based, in part, on variance in stroke width.

In some embodiments, automatic shadow removal module **240** may operate on binarized MSER text fragments/ blocks output by verification module **230** to determine the presence of shadows. In some embodiments, automatic shadow removal module **240** may obtain a neighborhood region around a binarized MSER text fragment and may detect the presence of a shadow in the neighborhood region around the MSER fragment in a manner consistent with disclosed embodiments. In some embodiments, automatic shadow removal module **240** may apply an adaptive thresholding technique to obtain a rebinarized image, which may compensate for the presence of shadows and output the rebinarized image to character segmentation module **245**.

In some embodiments, character segmentation module **245** may slice a text region identified by a corresponding bounding box, based on language specific rules. As a consequence of the segmentation, a word or sequence of characters in the bounding box may be segmented into constituent individual characters. In some embodiments, character segmentation module **245** may also characterize the individual characters using feature vectors.

The output of character segmentation module **245** may be used by OCR module **250** to decode and recognize characters. For example, in one embodiment, the feature vectors may be input to multi-stage character decoder **253**, which may generate one or more characters as alternatives to one another, optionally with confidence measures for each character in the group as representing a character of text in a specific sub-block. Subsequent stages in multi-stage character decoder **253** may use a variety of techniques including context and/or heuristics along with the confidence measures to resolve any ambiguities. In some embodiments, each group of characters identified by the decoder, may be input to word decoder module **255**, which may collect such groups of characters for all sub-blocks in a block/bounding box corresponding to a text region, and output a word that has been selected from a dictionary (not shown). In some embodiments, the dictionary may hold a predetermined set of words and/or sequences of characters.

FIG. **3** shows a flowchart of an exemplary method **300** for processing text in the presence of shadows and/or non-uniform lighting conditions in a manner consistent with disclosed embodiments. In some embodiments, portions of method **300** may be performed by automatic shadow removal module **240**.

In some embodiments, a neighborhood region N around input binarized MSER text fragment **305** may be determined by subroutine **310**. In some embodiments, the neighborhood region N may be used for shadow detection. In some embodiments, the neighborhood region N around input binarized MSER text fragment **305** may be determined by subroutine **310** using binarized MSER text fragment **305** from classifier module **232**. In some embodiments, the neighborhood region N may be determined by expanding one or more boundaries of input MSER text fragment **305**, (e.g. the left and/or right boundary of input binarized MSER text fragment **305**) to encompass a shadowed region, which may include one or more other binarized MSER text fragments.

In some embodiments, neighborhood region N may be indicated by a user. For example, a user may mark neighborhood region N in an image captured by a camera on a Mobile Station. For example, a bounding box may be used to indicate neighborhood region N. In situations, where a neighborhood region N has been identified, in some embodiments, in step **310**, word boundaries may be identified within neighborhood region N and the method may proceed to step **320**.

Next, in subroutine **320**, the existence of shadows may be determined for the neighborhood region N around input binarized MSER text fragment **305**.

Next, in step **330**, if no shadows are detected ("No" in step **330**), then character segmentation module **245** may be invoked. If shadows are detected, ("Yes" in step **330**), then adaptive thresholding subroutine **340** may be invoked to operate on the neighborhood region around input binarized MSER text fragment **305**.

In some embodiments, adaptive thresholding subroutine **340** may operate to rebinarize the neighborhood region around input binarized MSER text fragment **305** by dividing the neighborhood region N in to sub-blocks and adaptively binarizing sub-blocks including text using local thresholds. In some embodiments, a local threshold may be associated with each sub-block. Accordingly, in some embodiments, adaptive thresholding subroutine **340** may compensate for the presence of shadows and output a rebinarized image, rebinarized based on the local sub-block thresholds, to character segmentation module **245**.

FIG. **4**A shows a flowchart of exemplary subroutine **310** for determining a neighborhood region N around an MSER fragment in a manner consistent with disclosed embodiments. In some embodiments, portions of subroutine **310** may be performed by automatic shadow removal module **240** using input binarized MSER text fragment **305**.

In some embodiments, neighborhood region N around an input binarized MSER fragment may be determined, at least in part, by extending the boundaries of the MSER fragment. For example, one or more boundaries of a bounding box around the MSER may be extended. In some embodiments, the boundaries, which may be substantially orthogonal to the general text direction, may be extended along the general text direction. In general, the MSER boundary, which may take the form of a bounding box, may be extended in one or more directions.

In step **510**, in some embodiments, pixel intensity ranges D_1^0 and D_2^0 along initial first and second boundaries B_1^0 and B_2^0, respectively, of input binarized MSER text fragment **305** may be determined. For example, in step **510**, the first boundary may be the left ("L") boundary and the second boundary may be the right ("R") boundary and pixel intensity ranges D_L^0 and D_R^0 along initial left and right boundaries B_L^0 and B_R^0, respectively, of input binarized MSER text fragment **305** may be determined.

In the following discussion, the terms "L" (left) and "R" (right) may be used to describe a first and second boundary to illustrate operation of the method when the boundaries are extended in two directions and for explanatory purposes only. However, the method is not limited to the examples discussed, and, in general, the method may be applied by extending boundaries of the MSER fragment and/or a bounding box around the MSER fragment in one or more directions.

Accordingly, in step **510**, pixel intensity ranges $D_{1=L}^0$ and $D_{2=R}^0$ along the initial left and right boundaries left and right boundaries $B_{1=L}^0$ and $B_{1=R}^0$, respectively, of input binarized MSER text fragment **305** may be determined. For example, the pixel intensity range D_L^0 at the initial left boundary B_L^0 of input binarized MSER text fragment **305** may be determined as $D_L^0=\max(P_L^0)=\min(P_L^0)$, where $\max(P_L^0)$ and $\min(P_L^0)$ are the maximum and minimum pixel intensities, respectively, of pixels at B_L^0. Similarly, the pixel intensity range D_R^0 at the initial right boundary B_R^0 of input binarized MSER text fragment **305** may be determined as $D_R^0=\max(P_R^0)-\min(P_R^0)$, where $\max(P_R^0)$ & $\min(P_R^0)$ are the maximum and minimum pixel intensities, respectively, of pixels at B_R^0.

In step **520**, boundary indicator i may be set to "L" (or 1) to indicate a left (or first) boundary and counter j, which may count the number of times the left (first) boundary is extended, may be set to 1. Further, a variable α, may be set to f, where 0<f<1.

Next in step **530**, in some embodiments, the left boundary may be extended to B_i^j and new pixel intensity range D_i^j may be computed at B_j^i. For example, for i=L, and j=1, the left boundary may be extended from B_L^0 to new boundary $B_i^j=B_{i=L}^{j=1}=B_L^1$ by moving boundary B_L^0 leftward by one or more pixels.

In some embodiments, a set comprising an ordered sequence of provisional first boundaries $B_1=\{B_{i=1}^j|j=1, 2, \ldots\}$ may be computed. In some embodiments, the ordered sequence of first boundaries may be obtained by expanding the MSER in a first direction to determine a first ordered sequence of provisional first boundaries $B_1=\{B_{i=1}^j|j=1, 2, \ldots\}$. For example, a set comprising an ordered sequence of provisional first boundaries $B_L=\{B_i^j|i=L; j=0, 1, \ldots\}$ may be computed and stored in an array, list, or other suitable data structure. For example, the MSER may be expanded in a first direction to determine a first ordered sequence of provisional first boundaries $B_L=\{B_L^j|j=1, 2, \ldots\}$ and the first provisional first boundary B_L^1 in the ordered sequence may be selected and the new pixel intensity range D_L^1 may be computed at B_L^1.

In step **540**, in some embodiments, the dynamic range D_i^j at the new provisional first boundary B_i^j may be compared as with a threshold determined by $\alpha*D_i^{j-1}$. Accordingly in step **540**, it may be determined whether $D_i^j \geq \alpha*D_i^{j-1}$. For example, in step **540**, for a first iteration where i=L and j=1, the dynamic range $D_i^j=D_{i=L}^{j-1}$ at the new provisional first boundary $B_i^j=B_{i=L}^{j-1}$ may be compared with a threshold determined by $\alpha*D_{i=L}^{(1-1)}=\alpha*D_L^0$, it may be determined whether $D_L^1 \geq \alpha*D_L^0$.

As noted above, for example, for the first direction (where i=1), α may be set to f, where 0<f<1. In some embodiments, α may be a function of the pixel intensity range of a boundary in the previous iteration.

If $D_i^j \geq \alpha*D_i^{j-1}$ ("Yes" in step **540**), then, in step **545**, the counter j is incremented and the method returns to step **530** to begin another iteration. On the other hand, if $D_i^j<\alpha*D_i^{j-1}$ ("No" in step **540**), then, in step **550**, the value of boundary indicator i may be checked.

If i=L ("Yes" in step **550**), then, in step **560**, the left boundary of the neighborhood region B_L^N around input binarized MSER text fragment **305** is set to $B_L^N=B_i^j$. Further, in some embodiments, a left word boundary B_L^W may be set as $B_{i=L}^W=B_i^{j-1}$. The left word boundary B_L^W may indicate the left end of a word in neighborhood region N **570**.

In step **562**, boundary indicator i may be set to 2 or "R" to indicate a second (e.g. right) direction, the counter j which now counts the number of times the second boundary is extended, may be set to 1. Further, variable α, may be set to g, where 0<g<1.

In some embodiments, the method may then return to step **530** to begin a next set of iterations to extend the second boundary B_R^0, which may be the right ("R") boundary B_R^0 of input MSER fragment **305**.

In some embodiments, a set comprising an ordered sequence of provisional second boundaries $B_2=\{B_{i=2}^j|j=1, 2, \ldots\}$ may be computed. In some embodiments, the ordered sequence of second boundaries may be obtained by expanding input MSER fragment **305** in a second direction to determine a second ordered sequence of provisional second boundaries $B_2=\{B_{i=2}^j|j=1, 2, \ldots\}$. For example, a set comprising an ordered sequence of provisional second boundaries $B_R=\{B_i^j|i=R; j=0, 1, \ldots\}$ may be computed and stored in an array, list, or other suitable data structure. For example, the MSER may be expanded in a second direction to determine a second ordered sequence of provisional first boundaries $B_R=\{B_R^j|j=1, 2, \ldots\}$. At the beginning of the next iteration, the first provisional second boundary B_R^1 may be selected and the new pixel intensity range D_R^1 may be computed at B_R^1. In some embodiments, the method may iterate through steps **530**, **540** and **545** until $D_i^j<\alpha*D_i^{j-1}$, or $D_R^j<\alpha*D_R^{j-1}$.

In step **550**, if the value of indicator i=R (i≠ "L"/"No" in step **550**), then, in step **570**, the right boundary of neighborhood N may be set as $B_R^N=B_i^j$. Further, in some embodiments, a right word boundary B_R^W may be set as $B_R^W=B_{i=R}^{j-1}$. The right word boundary B_R^W may indicate the right end of the word. Thus, neighborhood image N **570** around input binarized MSER text fragment **305** may be delimited, at least in part, by left and right boundaries B_L^N and B_R^N, respectively. Similarly, in one embodiment, the right and left word boundaries may be delimited by B_L^W and B_R^W. The method may then proceed to subroutine **320**.

In some embodiments, method **310** may iteratively grow the left and/or right boundaries around input binarized MSER text fragment **305** to determine neighborhood N **570**. In some embodiments, one of the iteratively grown regions may be identified as neighborhood N **570** when the pixel intensity range at the left and right boundaries B_L^N and B_R^N, respectively, of neighborhood N **570** satisfy conditions $D_L^j<f*D_L^{j-1}$ and $D_R^k<g*D_R^{k-1}$, respectively, for positive integers j, k. In some embodiments, a plurality of boundaries may be determined in parallel. For example, the right and left boundaries B_L^N and B_R^N, respectively, of neighborhood N **570** may be determined in parallel.

FIG. **4B** illustrates expansion of the boundaries exemplary binarized output MSER fragment **118**. As shown in FIG. **4B**, binarized output fragment **118** may be grown by expanding boundaries B_L^0 and B_R^0. For example, MSER fragment **118** may be expanded from initial first/left MSER boundary B_L^0 to provisional first/left boundaries B_L^1, B_L^2, . . . B_L^N, where B_L^N N **572** represents the first/left boundary of neighborhood region **570**. Similarly, MSER fragment **118** may be expanded from initial second/right MSER boundary B_R^0 to provisional second/right boundaries B_R^1, B_R^2, . . . B_R^N, where B_R^N **574** represents the second/right boundary of neighborhood region **570**. In some embodiments, the iterative expansion of the boundaries exemplary binarized output MSER fragment **118** (e.g. as shown in FIG. **4B**) may be performed by method **310**.

FIG. **4C** illustrates the result of expanding exemplary binarized output fragment **118** to neighborhood region N **570**. As shown in FIG. **4B**, binarized output fragment **118** may be grown to neighborhood region N **570**. For example, in some embodiments, method **310** may be applied to binarized output fragment **118** to grow binarized output fragment **118** neighborhood region N **570** delimited, at least in part, by boundaries B_L^N and B_R^N. For example, in some embodiments, method **310** may iteratively grow the left and/or right boundaries around input binarized MSER text fragment **118** to determine neighborhood N **570** with boundaries B_L^N **572** and B_R^N **574**.

FIG. **4**C illustrates image intensities at the left and right boundaries B_L^N **572** and B_R^N **574**, respectively of neighborhood region N **570** around an MSER fragment. As shown in FIG. **4**B, there is less variation in pixel intensity values at boundaries B_L^N **572** and B_R^N **574**, of neighborhood N **570** relative to pixels located on lines **576** and **577**, which include text. The presence of text increases intensity variations in the image, which is shown in the graphs in FIG. **4**D.

FIG. **4**D shows a graph plotting pixel intensities at locations on lines **572**, **576** and **577** for neighborhood region N **570** shown in FIG. **4**C. As shown in FIG. **4**D, the average pixel intensity level for pixels located on line **577** is lower than the average pixel intensity level for pixels located on line **576** because of the presence of shadows. However, as shown in FIG. **4**D, pixel intensities on both lines **576** and **577** show variations in image intensities because of the presence of text at those locations. On the other hand, there is relatively little variation in pixel intensities at values at boundary B_L^N **572** of neighborhood N **570** because no text is present on B_L^N **572**. In some embodiments, the variation in pixel intensities at locations around an MSER text fragment (e.g. text fragment **118**) may be used to determine a neighborhood region (e.g. N **570** delimited by boundaries B_L^N and B_R^N) around the MSER text fragment.

FIG. **5**A shows a flowchart of an exemplary method **600** for determining the presence of a shadow in a neighborhood region around an MSER fragment in a manner consistent with disclosed embodiments. In some embodiments, method **600** may be performed, in part, by routines **320** and **330**.

In some embodiments, neighborhood image N **570** with boundaries B_L^N and B_R^N, may be input to method **600**. In step **323**, the absolute average pixel intensity difference P_D^N between boundaries B_L^N and B_R^N may be computed as $P_D^N=|\text{avg}[P(B_L^N)]-\text{avg}[P(B_R^N)]|$. For example, the average intensity ($\text{avg}[P(B_L^N)]$) at B_L^N may be subtracted from the average intensity ($\text{avg}[P(B_R^N)]$) at B_R^N. P_D^N, the average absolute intensity difference, may then be obtained as the absolute value of the difference. In some embodiments, a measure of shadow extent may be obtained based, in part on P_D^N.

Next, in step **333**, the absolute average pixel intensity difference P_D^N may be compared with an intensity difference threshold $\Delta_{threshold}^P$. In step **333**, if $P_D^N>\Delta_{threshold}^P$ ("Yes" in step **333**), then it may be determined that a shadow is present and the method proceeds to subroutine **340**. On the other hand, in step **333**, if $P_D^N\leq\Delta_{threshold}^P$ ("No" in step **333**), then it may be determined that no shadow is present and the binarized image may be output to character segmentation module **245**.

FIG. **5**B shows a flowchart of another exemplary method **625** for determining the presence of a shadow in a neighborhood region around an MSER fragment in a manner consistent with disclosed embodiments. In some embodiments, method **625** may be performed, in part, by routines **320** and **330**.

In some embodiments, neighborhood image N **570** with boundaries B_L^N and B_R^N, may be input to method **600**. In step **325**, the entropy of the pixel intensity histogram for neighborhood N **570** may be computed. In some embodiments, the entropy of the pixel intensity histogram may be computed by placing the grayscale pixel values into 256 bins ranging from 0-255. A probability distribution of intensity values may be obtained by normalizing the bins. For example, normalization may be performed by dividing the number of pixels in each bin by the total number of pixels in the neighborhood image N **570** to obtain ρ_i, where ρ_i is the normalized value of bin i in the histogram and represents the probability that a pixel in neighborhood N will have intensity i and

$$\sum_{i=0}^{255}\rho_i=1.$$

The entropy E^N of the probability distribution may be calculated as

$$E^N=\sum_{i=0}^{255}-\rho_i\log_2\rho_i.$$

In some embodiments, a measure of shadow extent may be obtained based, in part on entropy E^N.

In step **335**, E^N is compared with entropy threshold $E_{threshold}$. In step **335**, if $E^N>E_{threshold}$ ("Yes" in step **335**), then it may be determined that a shadow is present and the method proceeds to subroutine **340**. On the other hand, in step **335**, if $E^N\leq E_{threshold}$ ("No" in step **335**) then it may be determined that no shadow is present and the method proceeds to character segmentation module **245**.

FIG. **5**C shows a flowchart of an exemplary method **650** for determining the presence of a shadow in a neighborhood region around an MSER fragment in a manner consistent with disclosed embodiments. In some embodiments, method **650** may be performed, in part, by routines **320** and **330**.

In some embodiments, neighborhood image N **570** with boundaries B_L^N and B_R^N, may be input to method **650**. In step **327**, a distribution of pixel intensity values for neighborhood N **570** may be determined. For example, a histogram of pixel intensity values in neighborhood N **570** may be obtained by placing the grayscale pixel values of pixels in neighborhood N **570** into 256 bins ranging from 0-255. A probability distribution of intensity values may be obtained by normalizing the bins. For example, normalization may be performed by dividing the number of pixels in each bin by the total number of pixels in the image to obtain ρ_i, where ρ_i is the normalized value of bin i in the histogram and represents the probability that a pixel in neighborhood N will have intensity i and

$$\sum_{i=0}^{255}\rho_i=1.$$

In some embodiments, pixel intensity values for pixels in neighborhood N **570** may be grouped into ranges, so that the total number of bins may be less than 256. Accordingly, ρ_i, which is the normalized value of bin i in the histogram, is the probability that a pixel in neighborhood N will fall in the range of intensity values represented by bin i and

$$\sum_{i=0}^{255}\rho_i=1.$$

In some embodiments, a measure of shadow extent may be obtained based, in part on analysis of the distribution of pixel intensity values for neighborhood **570**.

FIG. **5**D shows a histogram of pixel intensity values in a neighborhood region around an MSER fragment for an exemplary image without a shadow, while FIG. **5**E shows a histogram of pixel intensity values in a neighborhood region around an MSER fragment for an exemplary image with a shadow. When no shadows are present in neighborhood region N **570**, the distribution of pixel intensity values is typically bi-modal being distributed between text and non-text intensity values. For example, as shown in FIG. **5**D, pixel intensity values may be broadly classified into two groups as shown by the dark lines. The two groups comprise lower pixel intensity group **605** (with pixel intensity values between 44 and 60) and higher pixel intensity group **610** (values between 128 and 140), respectively. Shadows have the effect of increasing the spread of the distribution. For example, as shown in FIG. **5**E, pixel intensities are in three pixel intensity groups **615**, **620** and **625**, including strong central group **620** clustered around the midpoint 128 of the pixel intensity range (which ranges from 0 through 255).

Referring to FIG. **5**C, accordingly, in some embodiments, in step **337**, the histogram may be examined for a strong central peak. For example, if the histogram shows a strong group of pixel intensities clustered around the midpoint of pixel intensity values ("Yes" in step **337**), then, in step **337**, it may be determined that a shadow is present and the method proceeds to subroutine **340**. When no strong central peak is detected and/or the pixel intensity distribution is determined to be bi-modal, then, ("No" in step **337**), it may be determined that a shadow is not present and the method proceeds character segmentation module **245**.

FIG. **6**A shows a flowchart for an exemplary method **340** for adaptive thresholding in a manner consistent with disclosed embodiments. In some embodiments, subroutine **340** may be invoked if a shadow is determined to be present by one or more of methods **600**, **625** and/or **650**. In some embodiments, portions of subroutine **340** may be performed by automatic shadow removal module **240**.

In some embodiments, neighborhood N **570** with boundaries B_L^N and B_R^N, may be input to subroutine **340**. In step **710**, neighborhood N **570** may be divided into sub-blocks. For example, in one embodiment, neighborhood N **570** may be divided into equal sized sub-blocks, where the size of each sub-block may be set as k*stroke-width, where k is a heuristic and k>1, which ensures that sub-block size is greater than stroke width. Stroke width may be defined as the thickness of a character outline relative to height and is a reflection of text size relative to overall character structure. The term "stroke" refers to a characteristic of text. Stroke may be viewed as a connected component, which may take the form of a band of approximately constant width. FIG. **6**B shows exemplary neighborhood N **570** with boundaries B_L^N **572** and B_R^N **574** divided into equal sized sub-blocks. In some embodiments, neighborhood N **570** with boundaries B_L^N **572** and B_R^N **574** divided into equal sized sub-blocks (e.g. as shown in FIG. **6**B) may be obtained after step **710**.

In step **720**, a subset of sub-blocks in neighborhood N **570** that include text may be determined. For example, a variance of pixel intensity values may be computed for each sub-block in neighborhood N **570**. If the variance of pixel intensity values exceeds some threshold variance, then the sub-block may be flagged as containing text.

Next, in step **730**, an individual binarization threshold may be determined for each sub-block in the subset of sub-blocks with text in neighborhood N **570** that contain text. For example, each sub-block with text S_i may be associated with a corresponding binarization threshold T_i. The binarization threshold T_i, which corresponds to sub-block with text S_i may be used to binarize sub-block S_i. For example, Otsu's method may be used to binarize each sub-block S_i in the subset and calculate the corresponding binarization threshold T_i for the sub-block. Otsu's method assumes that the image (sub-block containing text) to be thresholded contains two classes of pixels or a bi-modal histogram (e.g. foreground and background) and calculates an optimal threshold to separate the two classes so that their combined intra-class variance is minimized. As a consequence of the sub-block binarization, thresholded neighborhood image N_T may be obtained.

In step **740**, words/connected components may be extracted from the thresholded neighborhood image N_T using flood fill. Flood fill uses a start node or start pixel and a target color to determine pixels in thresholded neighborhood image N_T that are connected to the start pixel by a path given by the target color. Pixels in each path (connected component) may be changed to a replacement color. In some embodiments, the start node may be selected from a region in N_T within MSER fragment **305**. Thus, in the embodiments above, as a consequence of flood fill, a CC comprising all pixels in thresholded neighborhood image N_T that are connected by a path to the selected pixel (which is located within MSER fragment **305**) are extracted.

Following flood fill and word/CC extraction, the values of pixels in original neighborhood image N **570** that correspond to pixels in the flood fill extracted CCs may be checked for color variations. Typically, the presence of shadows is accompanied by color variations in connected components. For example, in step **740**, the extracted CCs in neighborhood image N **570** may be checked for color variations. If shadows are present, color variations (such as light and dark regions across text) may be present. If shadows are not present, the variations in extracted text pixels may be minimal. In some embodiments, if the color variations in the extracted CCs are determined to not exceed a predetermined amount, ("No" in step **740**), then, the method proceeds to character segmentation module **245**. In some embodiments, step **740** may identify false positives for shadow presence.

In some embodiments, if color variations in the extracted CCs are determined to exceed some predetermined amount, ("Yes" in step **740**), then, in step **750**, noise filtering may be applied to the sub-block based thresholded neighborhood image. In some embodiments, noise filtering may identify and filter out points (noise) whose color values are different from the text color by rebinarizing these points.

In one embodiment, the text color value for extracted CC pixels at word boundaries B_L^W and B_R^W, respectively, may be used to identify outliers. For example, in one embodiment, in step **750**, text points in the extracted CCs may be clustered based on the color values for extracted CC pixels at word boundaries B_L^W and B_R^W, respectively.

Text colors may differ in the shadow and non-shadow regions. Further, text color values for extracted CC pixels at word boundaries B_L^W and B_R^W are known. Accordingly, values of pixels in original neighborhood image N **570** that correspond to pixels in the flood fill extracted CCs may be read and compared with text color values at word boundaries B_L^W and B_R^W. In some embodiments, based on the results of the comparison the pixels may be divided into two sets (or clusters). For example, the pixels may be separated in to two sets based on their distance from text color values at word boundaries B_L^W and B_R^W. In one embodiment, a fraction (e.g. 10%) of the pixels in a set may selected as outliers based on the extent to which they differ from the average or median text color value for that set.

Further, a set of outlier points comprising points that lie outside the two clusters may be determined. Next, in some embodiments, an edge detector may be used to determine adjacent sub-block boundaries where noise may be present. The points identified by edge detector and the set of outlier points may then be rebinarized in step **750** to reduce noise.

In step **760**, the noise filtered image may be flood filled to extract a primary word/CC. The primary word may be clustered with any remaining CCs in the noise filtered image. In some embodiments, clustering rules, such as those used clustering rules module **214** may be used to cluster a plurality of CCs that are part of a word into a new single clustered connected component. For example, for Devanagari, CCs disconnected due to diacritical marks (maatras), broken letters, half-words etc. may be clustered to form a single CC. In general, context and other rules may be used to cluster a plurality of CCs that are part of a word to form a new single clustered connected component. The resulting binarized image **770** may then be output.

FIG. **6**C shows an exemplary flowchart for a method **790** for processing text in the presence of shadows and/or non-uniform lighting conditions in a manner consistent with disclosed embodiments. In some embodiments, input binarized MSER text fragment **305** may be input to method **790**.

In step **792**, a Maximally Stable Extremal Region (MSER) in an image may be expanded to obtain a neighborhood associated with the MSER, wherein the neighborhood may comprise a plurality of sub-blocks. For example, input binarized MSER text fragment **305** may be expanded, in step **792** to obtain a neighborhood **570** associated with the MSER, where neighborhood **570** may comprise a plurality of sub-blocks.

In some embodiments, expanding the MSER may comprise: expanding the MSER in a first direction to determine a first ordered sequence of provisional first boundaries ($B_{i=1}^{j}$, j=1, 2, . . .) and expanding the MSER in a second direction to determine a second ordered sequence of provisional second boundaries ($B_{i=2}^{k}$, k=1, 2, . . .) of the neighborhood; and selecting one of the provisional first boundaries ($B_{i=1}^{j=p}$) in the first ordered sequence and one of provisional second boundaries ($B_{i=1}^{k=q}$) in the second ordered sequence as a first and second boundary of the neighborhood, respectively, wherein the first boundary satisfies $D_{i=1}^{j=p}<f*D_{i=1}^{p-1}$, where $0<f<1$, and the second boundary satisfies $D_{i=1}^{k=q}<g*D_{i=2}^{q-1}$, where $0<g<1$.

In some embodiments, the method may further comprise, detecting the presence of a shadow in the neighborhood by performing at least one of: a comparison of an absolute average pixel intensity difference between the first and second boundaries with an intensity difference threshold; or a comparison of an entropy of a pixel intensity histogram for the neighborhood with an entropy threshold; or an analysis of a pixel intensity distribution in the pixel intensity histogram for the neighborhood.

In some embodiments, in step **794**, a subset of the plurality of sub-blocks in the neighborhood may be thresholded, the subset comprising sub-blocks with text, wherein each sub-block in the subset is thresholded using a corresponding local threshold associated with the sub-block. For example, each sub-block may have a corresponding local threshold associated with the sub-block. Sub-blocks with text may be thresholded using the corresponding local threshold associated with the sub-block.

In some embodiments, the sub-blocks with text may be determined by comparing a variance of pixel intensity values in the sub-block with a pixel intensity variance threshold. In some embodiments, the local threshold associated with the sub-block may be determined by applying Otsu's method to the sub-block. In some embodiments, the sub-blocks may be of equal size and may be a multiple of a stroke width parameter, wherein the stroke width parameter is indicative of the thickness of a character's outline relative to the character's height.

In some embodiments, a thresholded neighborhood may be obtained in step **796**. In some embodiments, the method may further comprise, applying flood fill to extract a connected component (CC) associated with the thresholded neighborhood based, at least in part, on a start pixel in the MSER region; determining that color variations present in the extracted connected component exceed a color variation threshold; and applying noise filtering to the thresholded neighborhood.

FIG. **7**A shows a camera captured image **777** and a camera image captured with flash **787** with the flash set at an adjusted illumination level. As shown in FIG. **7**A, camera captured image **777** comprises shadows. In some embodiments, a user may provide input, such as by drawing bounding box **788**, to indicate a shadowed region in the image. In some embodiments, a measure of shadow extent in the image region may be obtained and camera image captured with flash **787** may be obtained by adjusting an illumination level of the flash based on the measure of shadow extent. Camera image captured with flash **787** may then be obtained, for example, by capturing a subsequent image by using flash with the adjusted illumination level of the flash.

FIG. **7**B shows a method **775** for compensating for the presence of shadows and/or non-uniform lighting in a camera captured image **777**. In some embodiments, in step **780**, camera captured image **77** may be processed to obtain a region in an image captured by the camera, the image region being obtained, at least in part, based on user input.

In step **785**, a measure of shadow extent in the image region may be obtained. For example, a measure of shadow extent may be obtained based, at least in part, on at least one of: a comparison of an absolute average pixel intensity difference between the first and second boundaries with an intensity difference threshold; or a comparison of an entropy of a pixel intensity histogram for the neighborhood with an entropy threshold; or an analysis of a pixel intensity distribution in the pixel intensity histogram for the neighborhood. For example, portions of one of methods, **600**, **625** and/or **650** (such as routines **323**, **325** and/or **327**) may be used to obtain a measure of shadow extent in the image region.

In some embodiments, camera image captured with flash **787** may be obtained by adjusting an illumination level of the flash based on the measure of shadow extent. Camera image captured with flash **787** may then be obtained, for example, by capturing a subsequent image by using flash with the adjusted illumination level of the flash.

FIG. **8** shows schematic block diagram illustrating certain exemplary features of an exemplary mobile device Mobile Station (MS) **800** that may be used facilitate robust and accurate recovery of words and/or characters reliably in the presence of non-uniform lighting and/or shadows in a manner consistent with embodiments disclosed herein. MS **800** may take the form of a smartphone, handheld computing device, laptop, notebook, tablet computer, portable computer, and/or a gaming device. In some embodiments, MS

800 may perform one or more of system **200**, and/or methods **300**, **310**, **340**, **600**, **625**, **650**, **790** and/or **775** in whole, or in part.

Mobile Station (MS) **800** may, for example, include: one or more processors **802**, memory **804**, removable media drive **820**, display **870**, camera(s) **830** and, as applicable, flash **838**, various sensors **836**, which may be operatively coupled using one or more connections **806** (e.g., buses, lines, fibers, links, etc.).

In some embodiments, MS **800** may implement one or more of portions of system **200**, and/or methods **300**, **310**, **340**, **600**, **625**, and/or **650** in a manner consistent with disclosed embodiments. For example, processors **802** on MS **800** may comprise Text Processing Module **816**, which may implement one or more of portions of system **200**, and/or methods **300**, **310**, **340**, **600**, **625**, and/or **650** in a manner consistent with disclosed embodiments by processing images captured by cameras **830**.

In some embodiments, display **870** (shown in FIG. **7** by the dashed block) may permit the display of visual output. Touchscreen **872** may permit users to input data via some combination of virtual keyboards, icons, menus, or other Graphical User Interfaces (GUIs), user gestures and/or input devices such as styli and other writing implements. In some embodiments, touchscreen **872** may overlay display **870**, which may concurrently display input entered by a user, images such as image **112-1** captured by camera(s) **830**, and/or provide other visual feedback based on the input. In some embodiments, touchscreen **872** may be implemented, for example, using a pressure sensitive screen such as a capacitive or resistive touchscreen. In some embodiments, display **870** may be implemented using a Liquid Crystal Display (LCD) display or a Light Emitting Diode (LED) display, such as an Organic LED (OLED) display. In other embodiments, display **870** may be a wearable display, which may be operationally coupled to, but housed separately from, other functional units in MS **800**. In some embodiments, touchscreen **872** may form part of a user input functional unit or module, which may include a combination of hardware and software components to receive input.

Camera(s) **830** may comprise one or more still and/or video image cameras and may incorporate sensors such as CCD and/or CMOS sensors. In some embodiments, camera(s) **830** may be coupled to flashes **838**, which may take the form of an electronic flash or other high-intensity illumination devices. In some embodiments, the intensity of flashes **838** may be adjustable. For example, in one embodiment, the intensity of flashes **838** may be adjusted, at least in part, by processors **802** based on a measure of shadow extent in a region of an image captured by camera **830**. In some embodiments, the intensity of flashes **838** may also be adjusted based on input from sensors **836**, such as, but not limited to, an ambient light sensor. In some embodiments, the duration of flashes **838** may also be adjusted.

Processors **802** may be implemented using a combination of hardware, firmware, and software. In some embodiments, processing unit **802** may include Text Processing Module **816**, which may facilitate robust and accurate recovery of words and/or characters reliably in the presence of non-uniform lighting and/or shadows in a manner consistent with embodiments disclosed herein. In some embodiments, processors **802** may perform and/or implement one or more of system **200**, and/or methods **300**, **310**, **340**, **600**, **625**, **650**, **790** and/or **775** in whole, or in part.

In some embodiments, Text Processing Module **816** may facilitate robust and accurate recovery of words and/or characters from images (such as image **112-1**) captured by camera **830** in the presence of shadows. In some embodiments, Text Processing Module **816** may perform and/or implement one or more of system **200**, and/or methods **300**, **310**, **340**, **600**, **625**, **650**, **790** and/or **775** in whole, or in part.

In some embodiments, neighborhood region N **571** may be indicated by a user in captured image **112-1**, which includes text with shadows. For example, a user may mark neighborhood region N **571** in image **112-1** captured by camera **830** on MS **800** using touchscreen **872**. For example, a bounding box (shown by heavy lines in FIG. **7**) may be used by a user to indicate neighborhood region N **788**. For example, referring to FIG. **3**, in instances, where neighborhood region N **571** has been identified (e.g. by user input) in some embodiments, Text Processing Module **816** may identify word boundaries within neighborhood region N **571** in step **310**, and the method may proceed directly to step **320**.

In some embodiments, image **112-1**, which contains shadows may be captured by cameras **830** and displayed on display **870**. In some embodiments, a user may provide input, such as by drawing bounding box **788**, to indicate a shadowed region in the image. In some embodiments, a measure of shadow extent in the image region may be obtained by processors **802** and/or text processing module **816** and camera image captured with flash **787** may be obtained by adjusting an illumination level of the flash based on the measure of shadow extent. Camera image captured with flash **787** may then be obtained, for example, by capturing a subsequent image by using flash with the adjusted illumination level of the flash.

In one embodiment, Text Processing Module **816** may process user input received using touchscreen **872**, which may capture the coordinates of the points of contact, time(s) or time period(s) associated with each point contact, the sequence in which the points of contact occurred, and/or other parameters associated with each point of contact. The points of contact and parameters associated with each point of contact and/or a set of points of contact may be relayed to Text Processing Module **816**, which may use the points of contact and parameters to interpret user gestures to determine bounding box **571** or other user input.

Processors **802** may also be capable of processing other information either directly or in conjunction with one or more other functional blocks shown in FIG. **7**. For example, processors **802** may process and combine raw measurements from sensors **836**. Sensors **836** may include touch sensors including multi-touch sensors, acoustic sensors such as microphones and speakers, ambient light sensors, and various others, which, in some instances, may be coupled to display **870** and/or touchscreen **872**. For example, in one embodiment, input from the ambient light sensor may be used to adjust the brightness of display **870**. In some embodiments, processors **802** may represent one or more circuits configurable to perform at least a portion of a computing procedure or process related to Text Processing Module **816** in a manner consistent with disclosed embodiments.

The methodologies described herein may be implemented by various means depending upon the application. For example, these methodologies may be implemented in hardware, firmware, software, or any combination thereof. For a hardware implementation, processors **802** may be implemented within one or more application specific integrated circuits (ASICs), digital signal processors (DSPs), digital signal processing devices (DSPDs), programmable logic devices (PLDs), field programmable gate arrays (FPGAs), controllers, micro-controllers, microprocessors, embedded processor cores, electronic devices, other electronic units designed to perform the functions described herein, or a combination thereof.

For a firmware and/or software implementation, the methodologies may be implemented using procedures, functions, and so on that perform the functions described herein. Any non-transitory machine-readable medium tangibly embodying instructions may be used in implementing the methodologies described herein. Non-transitory computer-readable media may include physical computer storage media. A storage medium may be any available medium that can be accessed by a computer. In one embodiment, software code pertaining to Text Processing Module **816** may be stored in a non-transitory computer-readable medium and read using removable media drive **820** and executed by at least one of processors **802**. For example, the methods and/or apparatuses presented herein may take the form in whole or part of a computer-readable medium that may include program code to support Text Processing Module **816** in a manner consistent with disclosed embodiments.

Non-transitory computer-readable media may include a variety of physical computer storage media. By way of example, and not limitation, such non-transitory computer-readable media can comprise RAM, ROM, EEPROM, CD-ROM or other optical disk storage, magnetic disk storage or other magnetic storage devices, or any other medium that can be used to store desired program code in the form of instructions or data structures and that can be accessed by a computer; disk and disc, as used herein, includes compact disc (CD), laser disc, optical disc, digital versatile disc (DVD), floppy disk and Blu-ray disc where disks usually reproduce data magnetically, while discs reproduce data optically with lasers. Combinations of the above should also be included within the scope of computer-readable media.

Memory **804** may be implemented within processors **802** and/or external to Processor **802**. As used herein the term "memory" refers to any type of long term, short term, volatile, nonvolatile, or other memory and is not to be limited to any particular type of memory or number of memories, or type of media upon which memory is stored. In general, memory **804** may represent any data storage mechanism. Memory **804** may include, for example, a primary memory and/or a secondary memory. Primary memory may include, for example, a random access memory, read only memory, etc. While illustrated in FIG. **7** as being separate from processors **802**, it should be understood that all or part of a primary memory may be provided within or otherwise co-located/coupled with processors **802**. Memory **804** may hold instructions and data for processors **802**, which may used by Text Processing Module **816**. For example, memory **804** may hold program code for Text Processing Module **816**, databases, lookup tables, font tables, etc.

Secondary memory may include, for example, the same or similar type of memory as primary memory and/or one or more data storage devices or systems, such as, for example, flash/USB memory drives, memory card drives, disk drives, optical disc drives, tape drives, solid state memory drives, etc. In certain implementations, secondary memory may be operatively receptive of, or otherwise configurable to couple to a non-transitory computer-readable medium in removable drive **820**. In some embodiments, non-transitory computer readable medium may form part of memory **804**.

Further, exemplary MS **800** may be modified in various ways in a manner consistent with the disclosure, such as, by combining (or omitting) one or more of the functional blocks shown. For example, in some embodiments, MS **800** may comprise one or more of speakers, microphones, transceivers (e.g., wireless network interfaces), Satellite Positioning System (SPS) receivers etc. Further, in certain example implementations, portions of MS **800** may take the form of one or more chipsets, and/or the like.

In addition to storage on computer readable medium, instructions and/or data may be provided as signals on transmission media included in a communication apparatus. For example, a communication apparatus may include a transceiver having signals indicative of instructions and data. The instructions and data are configured to cause one or more processors to implement the functions outlined in the claims. That is, the communication apparatus includes transmission media with signals indicative of information to perform disclosed functions.

Reference is now made to FIG. **9**, which is a schematic block diagram illustrating a computing device **900** enabled to facilitate robust and accurate recovery of words and/or characters reliably in the presence of non-uniform lighting, contrast variations, and/or shadows in a manner consistent with embodiments disclosed herein. In some embodiments, computing device **900** may take the form of a server, desktop computer, workstation or other device. In some embodiments, computing device **900** may include, for example, one or more processing units **952**, memory **954**, storage **960**, and (as applicable) communications interface **990** (e.g., wireline or wireless network interface), which may be operatively coupled with one or more connections **956** (e.g., buses, lines, fibers, links, etc.). In certain example implementations, some portion of computing device **900** may take the form of a chipset, and/or the like. In some embodiments, computing device **900** may be wirelessly coupled to one or more MS' **800** over a wireless network (not shown), which may one of a WWAN, WLAN or WPAN. For example, in one embodiment, computing device **900** may receive images (e.g. image **112-1**) captured by a camera on MS **800** for processing and may process the images to recover of words and/or characters reliably in the presence of non-uniform lighting and/or shadows.

In some embodiments, computing device **900** may implement one or more of portions of system **200**, and/or methods **300**, **310**, **340**, **600**, **625**, and/or **650** in a manner consistent with disclosed embodiments. In some embodiments, the above methods may be performed by processing units **952** and/or Text Processing Module **966** based on images obtained by computing device **900**. For example, the above methods may be performed in whole or in part by processing units **952** and/or Text Processing Module **966** in conjunction with one or more functional units on computing device **900** and/or in conjunction with MS **800**. For example, computing device **900** may receive a sequence of captured images from MS **800** and may perform portions of one or more of system **200**, and/or methods **300**, **310**, **340**, **600**, **625**, and/or **650** in whole, or in part, using Text Processing Module **966**.

Communications interface **990** may include a variety of wired and wireless connections that support wired transmission and/or reception and, if desired, may additionally or alternatively support transmission and reception of one or more signals over one or more types of wireless communication networks. Communications interface **990** may include interfaces for communication with MS **800** and/or various other computers and peripherals. For example, in one embodiment, communications interface **990** may comprise network interface cards, input-output cards, chips and/or ASICs that implement one or more of the communication functions performed by computing device **900**. In some embodiments, communications interface **990** may also interface with MS **800** to send processed output, and/or receive images, data and/or instructions related to one or more of system **200**, and/or methods **300**, **310**, **340**, **600**, **625**, and/or **650**. In some embodiments, communications interface **990** may be coupled to a camera, scanner, and/or another imaging device and may receive images from the coupled device(s) comprising text for processing.

Processing units **952** may use some or all of the obtained information to perform the requested computations and/or to send the requested information and/or results to MS **800** via communications interface **990**. In some embodiments, processing units **952** may be implemented using a combination of hardware, firmware, and software. In some embodiments, processing unit **952** may include Text Processing Module **966**, which may implement one or more of portions of system **200**, and/or methods **300**, **310**, **340**, **600**, **625**, and/or **650** in a manner consistent with disclosed embodiments by processing obtained images. In some embodiments, processing unit **952** may represent one or more circuits configurable to perform at least a portion of a data signal computing procedure or process related to the operation of computing device **900**.

For example, Text Processing Module **966** may implement OCR and/or portions of system **200**, and/or methods **300**, **310**, **340**, **600**, **625**, and/or **650** based on obtained images. In some embodiments, one or more of the methods above may be invoked during the course of execution of various AR and/or OCR based applications.

The methodologies described herein in flow charts and message flows may be implemented by various means depending upon the application. For example, these methodologies may be implemented in hardware, firmware, software, or any combination thereof. For a hardware implementation, the processing unit **952** may be implemented within one or more application specific integrated circuits (ASICs), digital signal processors (DSPs), digital signal processing devices (DSPDs), programmable logic devices (PLDs), field programmable gate arrays (FPGAs), processors, controllers, micro-controllers, microprocessors, electronic devices, other electronic units designed to perform the functions described herein, or a combination thereof.

For a firmware and/or software implementation, the methodologies may be implemented with modules (e.g., procedures, functions, and so on) that perform the functions described herein. Any machine-readable medium tangibly embodying instructions may be used in implementing the methodologies described herein. For example, software may be stored in removable media drive **970**, which may support the use of non-transitory computer-readable media **958**, including removable media. Program code may be resident on non-transitory computer readable media **958** or memory **954** and may be read and executed by processing units **952**. Memory may be implemented within processing units **952** or external to the processing units **952**. As used herein the term “memory” refers to any type of long term, short term, volatile, nonvolatile, or other memory and is not to be limited to any particular type of memory or number of memories, or type of media upon which memory is stored.

If implemented in firmware and/or software, the functions may be stored as one or more instructions or code on a non-transitory computer-readable medium **958** and/or memory **954**. Examples include computer-readable media encoded with a data structure and computer-readable media encoded with a computer program. For example, non transitory computer-readable medium **958** including program code stored thereon may include program code to facilitate robust and accurate recovery of words and/or characters reliably in the presence of non-uniform lighting and/or shadows in a manner consistent with embodiments disclosed herein.

Computer-readable media may include a variety of physical computer storage media. A storage medium may be any available medium that can be accessed by a computer. By way of example, and not limitation, such non-transitory computer-readable media can comprise RAM, ROM, EEPROM, CD-ROM or other optical disk storage, magnetic disk storage or other magnetic storage devices, or any other medium that can be used to store desired program code in the form of instructions or data structures and that can be accessed by a computer; disk and disc, as used herein, includes compact disc (CD), laser disc, optical disc, digital versatile disc (DVD), floppy disk and Blu-ray disc where disks usually reproduce data magnetically, while discs reproduce data optically with lasers. Other embodiments of computer readable media include flash drives, USB drives, solid state drives, memory cards, etc. Combinations of the above should also be included within the scope of computer-readable media.

In addition to storage on computer readable medium, instructions and/or data may be provided as signals on transmission media to communications interface **990**, which may store the instructions/data in memory **954**, storage **960** and/or relayed the instructions/data to processing units **952** for execution. For example, communications interface **990** may receive wireless or network signals indicative of instructions and data. The instructions and data are configured to cause one or more processors to implement the functions outlined in the claims. That is, the communication apparatus includes transmission media with signals indicative of information to perform disclosed functions.

Memory **954** may represent any data storage mechanism. Memory **954** may include, for example, a primary memory and/or a secondary memory. Primary memory may include, for example, a random access memory, read only memory, non-volatile RAM, etc. While illustrated in this example as being separate from processing unit **952**, it should be understood that all or part of a primary memory may be provided within or otherwise co-located/coupled with processing unit **952**. Secondary memory may include, for example, the same or similar type of memory as primary memory and/or storage **960** such as one or more data storage devices **960** including, for example, hard disk drives, optical disc drives, tape drives, a solid state memory drive, etc. In some embodiments, storage **960** may comprise one or more databases, lookup tables (LUTs), and/or other files that may hold information to facilitate OCR, which may include robust and accurate recovery of words and/or characters reliably in the presence of non-uniform lighting and/or shadows in a manner consistent with embodiments disclosed herein. In some embodiments, information in the databases, LUTs, etc may be read, used and/or updated by processing units **952** and/or Text Processing Module **966** during various computations.

In certain implementations, secondary memory may be operatively receptive of, or otherwise configurable to couple to a computer-readable medium **958**. As such, in certain example implementations, the methods and/or apparatuses presented herein may be implemented in whole or in part using non transitory computer readable medium **958** that may include with computer implementable instructions stored thereon, which if executed by at least one processing unit **952** may be operatively enabled to perform all or portions of the example operations as described herein. In some embodiments, computer readable medium **958** may be read using removable media drive **970** and/or may form part of memory **954**.

Although the present disclosure is described in relation to the drawings depicting specific embodiments for instructional purposes, the disclosure is not limited thereto. Various adaptations and modifications may be made without departing from the scope. Therefore, the spirit and scope of the appended claims should not be limited to the foregoing description.

What is claimed is:

1. A processor-implemented method for text processing comprising:

expanding a Maximally Stable Extremal Region (MSER) in an image captured by a camera to obtain a neighborhood associated with the MSER, the neighborhood comprising a plurality of sub-blocks;

detecting a shadow in the neighborhood based, at least in part, on parameters associated with intensities of pixels in the neighborhood; and

when a shadow is detected in the neighborhood, thresholding a subset of sub-blocks of the plurality of sub-blocks in the neighborhood, the subset of sub-blocks comprising sub-blocks with text, wherein, to detect the sub-blocks with text, each sub-block in the subset of sub-blocks is thresholded using a corresponding local threshold associated with the sub-block.

2. The method of claim **1**, wherein expanding the MSER comprises:

expanding the MSER in a first direction to determine a first ordered sequence of provisional first boundaries ($B_{i=1}^{j}$, j=1, 2, . . .) of the neighborhood and expanding the MSER in a second direction to determine a second ordered sequence of provisional second boundaries ($B_{i\times 2}^{k}$, k=1, 2, . . .) of the neighborhood; and

selecting one of the provisional first boundaries ($B_{i=1}^{j=p}$) as a first boundary of the neighborhood and one of provisional second boundaries ($B_{i=1}^{k=q}$) as a second boundary of the neighborhood, wherein the first boundary satisfies $D_{i=1}^{j=p}<f*D_{i=1}^{p-1}$, where $0<f<1$, and the second boundary satisfies $D_{i=2}^{k=q}<g*D_{i=2}^{q-1}$, where $0<g<1$, wherein D_1^j is a measure of pixel intensity range at a j*th* provisional first boundary and D_2^k is a measure of pixel intensity range at a k*th* provisional second boundary.

3. The method of claim **2**, wherein detecting the shadow in the neighborhood comprises performing at least one of:

a comparison of an absolute average pixel intensity difference with an intensity difference threshold, the absolute average pixel intensity difference calculated as an absolute value of a difference between an average pixel intensity of the first boundary and an average pixel intensity of the second boundary; or

a comparison of an entropy of a pixel intensity histogram for the neighborhood with an entropy threshold; or

an analysis of a pixel intensity distribution in the pixel intensity histogram for the neighborhood.

4. The method of claim **1**, wherein the subset of sub-blocks with text are determined by comparing a variance of pixel intensity values in each sub-block in the plurality of sub-blocks with a pixel intensity variance threshold.

5. The method of claim **1**, wherein, for each sub-block in the subset of sub-blocks, the corresponding local threshold is determined by applying Otsu's method to the corresponding sub-block.

6. The method of claim **1**, wherein the plurality of sub-blocks are of equal size and wherein the size of each of the plurality of sub-blocks is based, in part, on a multiple of a stroke width parameter determined from one or more characters of text in the neighborhood, wherein the stroke width parameter is indicative of a thickness of a character's outline relative to the character's height.

7. The method of claim **1**, further comprising:

obtaining, based on the thresholding, a thresholded neighborhood;

applying flood fill to extract a connected component (CC) associated with the thresholded neighborhood based, at least in part, on a start pixel located in the MSER;

determining that color variations across a plurality of pixels in the neighborhood exceed a color variation threshold, wherein each of the plurality of pixels in the neighborhood corresponds to a distinct pixel in the extracted connected component; and

applying noise filtering to the thresholded neighborhood.

8. A Mobile Station (MS) comprising:

a camera, the camera to capture an image,

a processor coupled to the camera, wherein the processor is configured to:

expand a Maximally Stable Extremal Region (MSER) in the image to obtain a neighborhood associated with the MSER, the neighborhood comprising a plurality of sub-blocks;

detect a shadow in the neighborhood based, at least in part, on parameters associated with intensities of pixels in the neighborhood; and

when a shadow is detected in the neighborhood, threshold a subset of sub-blocks of the plurality of sub-blocks in the neighborhood, the subset of sub-blocks comprising sub-blocks with text, wherein, to detect the sub-blocks with text, each sub-block in the subset of sub-blocks is thresholded using a corresponding local threshold associated with the sub-block.

9. The MS of claim **8**, wherein to expand the MSER, the processor is configured to:

expand the MSER in a first direction to determine a first ordered sequence of provisional first boundaries ($B_{i=1}^{j}$, j=1, 2, . . .) of the neighborhood and expand the MSER in a second direction to determine a second ordered sequence of provisional second boundaries ($B_{i=2}^{k}$, k=1, 2, . . .) of the neighborhood; and

select one of the provisional first boundaries ($B_{i=1}^{j=p}$) as a first boundary of the neighborhood and one of provisional second boundaries ($B_{i=1}^{k=q}$) as a second boundary of the neighborhood, wherein the first boundary satisfies $D_{i=1}^{j=p}<f*D_{i=1}^{p-1}$, where $0<f<1$, and the second boundary satisfies $D_{j=2}^{k=q}<g*D_{j=2}^{q-1}$, where $0<g<1$, wherein D_1^j is a measure of pixel intensity range at a j*th* provisional first boundary and D_2^k is a measure of pixel intensity range at a k*th* provisional second boundary.

10. The MS of claim **9**, wherein to detect the shadow in the neighborhood, the processor is configured to perform at least one of:

a comparison of an absolute average pixel intensity difference with an intensity difference threshold, the absolute average pixel intensity difference calculated as an absolute value of a difference between an average pixel intensity of the first boundary and an average pixel intensity of the second boundary; or

a comparison of an entropy of a pixel intensity histogram for the neighborhood with an entropy threshold; or

an analysis of a pixel intensity distribution in the pixel intensity histogram for the neighborhood.

11. The MS of claim 8, wherein the processor is configured to:

determine sub-blocks with text by comparing a variance of pixel intensity values in each sub-block in the plurality of sub-blocks with a pixel intensity variance threshold.

12. The MS of claim 8, wherein the processor is configured to:

determine the local threshold associated with the sub-block by applying Otsu's method to the sub-block.

13. The MS of claim 8, wherein the plurality of sub-blocks are of equal size and wherein the size of each of the plurality of sub-blocks is based, in part, on a multiple of a stroke width parameter determined from one or more characters of text in the neighborhood, wherein the stroke width parameter is indicative of a thickness of a character's outline relative to the character's height.

14. The MS of claim 8, wherein the processor is further configured to:

obtain, based on the thresholding, a thresholded neighborhood;

apply flood fill to extract a connected component (CC) associated with the thresholded neighborhood based, at least in part, on a start pixel located in the MSER;

determine that color variations across a plurality of pixels in the neighborhood exceed a color variation threshold, wherein each of the plurality of pixels in the neighborhood corresponds to a distinct pixel in the extracted connected component; and

apply noise filtering to the thresholded neighborhood.

15. An apparatus comprising:

image capturing means, the image capturing means to capture an image, and

text processing means coupled to the image capturing means, the text processing means comprising:

means for expanding a Maximally Stable Extremal Region (MSER) in the image to obtain a neighborhood associated with the MSER, the neighborhood comprising a plurality of sub-blocks;

means for detecting a shadow in the neighborhood based, at least in part, on parameters associated with intensities of pixels in the neighborhood; and

means for thresholding a subset of sub-blocks of the plurality of sub-blocks in the neighborhood when a shadow is detected, the subset of sub-blocks comprising sub-blocks with text, wherein each sub-block in the subset of sub-blocks is thresholded using a corresponding local threshold associated with the sub-block.

16. The apparatus of claim 15, wherein means for expanding the MSER further comprises:

means for expanding the MSER in a first direction to determine a first ordered sequence of provisional first boundaries ($B_{i=1}^{j}$, j=1, 2, . . .) of the neighborhood;

means for expanding the MSER in a second direction to determine a second ordered sequence of provisional second boundaries ($B_{i=2}^{k}$, k=1, 2, . . .) of the neighborhood; and

means for selecting one of the provisional first boundaries ($B_{i=1}^{j=p}$) as a first boundary of the neighborhood and one of provisional second boundaries ($B_{i=1}^{k=q}$) as a second boundary of the neighborhood, wherein the first boundary satisfies $D_{i=1}^{j=p}<f*D_{i=1}^{p-1}$, where $0<f<1$, and the second boundary satisfies $D_{j=2}^{k=q}<g*D_{j=2}^{q-1}$, where $0<g<1$, wherein D_1^j is a measure of pixel intensity range at a j^th provisional first boundary and D_2^k is a measure of pixel intensity range at a k^th provisional second boundary.

17. The apparatus of claim 16, wherein the means for detecting the shadow comprises at least one of:

means for comparing an absolute average pixel intensity difference with an intensity difference threshold, the absolute average pixel intensity difference calculated as an absolute value of a difference between an average pixel intensity of the first boundary and an average pixel intensity of the second boundary; or

means for comparing an entropy of a pixel intensity histogram for the neighborhood with an entropy threshold; or

means for analyzing a pixel intensity distribution in the pixel intensity histogram for the neighborhood.

18. The apparatus of claim 15, wherein the subset of sub-blocks with text are determined by comparing a variance of pixel intensity values in each sub-block in the plurality of sub-blocks with a pixel intensity variance threshold.

19. The apparatus of claim 15, wherein means for thresholding the subset of sub-blocks comprises:

means for applying Otsu's method to each sub-block to determine the corresponding local threshold.

20. The apparatus of claim 15, wherein the plurality of sub-blocks are of equal size and, wherein the size of each of the plurality of sub-blocks is based, in part, on a multiple of a stroke width parameter determined from one or more characters of text in the neighborhood, wherein the stroke width parameter is indicative of a thickness of a character's outline relative to the character's height.

21. The apparatus of claim 15, further comprising:

means for obtaining, based on the thresholding, a thresholded neighborhood;

means for flood filling, the means for flood filling to extract a connected component (CC) associated with the thresholded neighborhood based, at least in part, on a start pixel located in the MSER;

means for determining that color variations across a plurality of pixels in the neighborhood exceed a color variation threshold, wherein each of the plurality of pixels in the neighborhood corresponds to a distinct pixel in the extracted connected component; and

means for applying noise filtering to the thresholded neighborhood.

22. A non-transitory computer-readable medium comprising instructions, which when executed by a processor, perform steps in a method for text processing comprising:

expanding a Maximally Stable Extremal Region (MSER) in an image captured by a camera to obtain a neighborhood associated with the MSER, the neighborhood comprising a plurality of sub-blocks;

detecting a shadow in the neighborhood based, at least in part, on parameters associated with intensities of pixels in the neighborhood; and

when a shadow is detected in the neighborhood, thresholding a subset of sub-blocks of the plurality of sub-blocks in the neighborhood, the subset of sub-blocks comprising sub-blocks with text, wherein, to detect the sub-blocks with text, each sub-block in the subset of sub-blocks is thresholded using a corresponding local threshold associated with the sub-block.

23. The computer-readable medium of claim 22, wherein expanding the MSER comprises:

expanding the MSER in a first direction to determine a first ordered sequence of provisional first boundaries

($B_{i=1}^{j}$, j=1, 2, . . .) of the neighborhood and expanding the MSER in a second direction to determine a second ordered sequence of provisional second boundaries ($B_{i=2}^{k}$, k=1, 2, . . .) of the neighborhood; and

selecting one of the provisional first boundaries ($B_{i=1}^{j=p}$) as a first boundary of the neighborhood and one of provisional second boundaries ($B_{i=1}^{k=q}$) in the second ordered sequence as a first and as a second boundary of the neighborhood, respectively, wherein the first boundary satisfies $D_{i=1}^{j=p}<f*D_{i=1}^{p-1}$, where $0<f<1$, and the second boundary satisfies $D_{i=2}^{k=q}<g*D_{i=2}^{q-1}$, where $0<g<1$, wherein D_1^j is a measure of pixel intensity range at a j*th* provisional first boundary and D_2^k is a measure of pixel intensity range at a k*th* provisional second boundary.

24. The computer-readable medium of claim **23**, wherein detecting the shadow in the neighborhood comprises performing at least one of:

a comparison of an absolute average pixel intensity difference with an intensity difference threshold, the absolute average pixel intensity difference calculated as an absolute value of a difference between an average pixel intensity on the first boundary and an average pixel intensity on the second boundary; or

a comparison of an entropy of a pixel intensity histogram for the neighborhood with an entropy threshold; or

an analysis of a pixel intensity distribution in the pixel intensity histogram for the neighborhood.

25. The computer-readable medium of claim **22**, wherein the subset of sub-blocks with text are determined by comparing a variance of pixel intensity values in each sub-block in the plurality of sub-blocks with a pixel intensity variance threshold.

26. The computer-readable medium of claim **22**, wherein, for each sub-block in the subset of sub-blocks, the corresponding local the local threshold associated with the sub-block is determined by applying Otsu's method to the corresponding sub-block.

27. The computer-readable medium of claim **22**, wherein the plurality of sub-blocks are of equal size and wherein the size of each of the plurality of sub-blocks is based, in part, on a multiple of a stroke width parameter determined from one or more characters of text in the neighborhood, wherein the stroke width parameter is indicative of a thickness of a character's outline relative to the character's height.

28. The computer-readable medium of claim **22**, further comprising:

obtaining, based on the thresholding, a thresholded neighborhood;

applying flood fill to extract a connected component (CC) associated with the thresholded neighborhood based, at least in part, on a start pixel located in the MSER;

determining that color variations across a plurality of pixels in the neighborhood exceed a color variation threshold, wherein each of the plurality of pixels in the neighborhood corresponds to a distinct pixel in the extracted connected component; and

applying noise filtering to the thresholded neighborhood.

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